

Óbuda University

PhD Thesis



OSI Model Interaction Integration
for
Reliable Fault Tolerance in Real-Time Communication
Sessions
with
A Performance Based Synchronization Algorithm

by

Stefano-Niko Orzen

Supervisor: Levente Adalbert Kovacs

Applied Informatics Doctoral School
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Statement

I, Stefano-Niko Orzen, hereby declare that I have written this PhD thesis myself, and have only used sources that have been explicitly cited herein. Every part that has been borrowed from external sources (either verbatim or reworded, but with essentially the same content) is unambiguously denoted as such, with a reference to the original source.

FOREWORD

This doctorate thesis was elaborated during my activity as a PhD student.

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List of Abbreviations

- [1] OSI = Open Systems Interconnection
- [2] QoS = Quality of Service
- [3] UTC = Universal Time Coordination
- [4] MAC = Media Access Control
- [5] ARP = Address Resolution Protocol
- [6] RARP = Reverse Address Resolution Protocol
- [7] STP = Spanning Tree Protocol
- [8] DNS = Domain Name System
- [9] DHCP = Dynamic Host Configuration Protocol
- [10] MPLS = Multiprotocol Label Switching
- [11] OSPF = Open Shortest Path First
- [12] IS - IS = Intermediate System - Intermediate System
- [13] IGRP = Interior Gateway Routing Protocol
- [14] AS - AS = Autonomous System - Autonomous System
- [15] BGP = Border Gateway Protocol
- [16] RTP = Real Time Protocol
- [17] RSVP = Resource Reservation Protocol
- [18] LAN = Local Area Network
- [19] MAN = Metropolitan Area Network
- [20] WAN = Wide Area Network
- [21] SAN = Storage Area Network
- [22] IP = Internet Protocol
- [23] TCP = Transmission Control Protocol
- [24] UDP = User Datagram Protocol
- [25] JMT = Java Modeling Tools
- [26] TTL = Time to Live
- [27] RTP = Real Time Protocol
- [28] RSVP = Resource Reservation Protocol
- [29] SSH = Secure Shell Protocol
- [30] HTTPS = Hypertext Transfer Protocol
- [31] VPN = Virtual Private Network
- [32] DoS = Denial of Service
- [33] CAIDA = Cooperative Association for Internet Data Analysis
- [34] NTP = Network Time Protocol
- [35] ITU = International Telecommunications Union
- [36] IETF = Internet Engineering Taskforce
- [37] IANA = Internet Assigned Numbers Authority
- [38] ICANN = Internet Corporation for Assigned Names and Numbers

I. INTRODUCTION

The purpose of this doctoral thesis is to complete the field of computer networks. In this study I approached the problem of persistent routing that falls in the session layer of data communications that are coordinated by the OSI model [ZIM80]. This problem was analyzed in terms of real-time communications, where research has a concise role and with effective applicability for the real world of information transmissions. During my documentation and analysis period I realized that persistent routes lack fault tolerant methods for intermediate transmissions, these representing hard points in data transmissions.

Because data communications in real-time are based on forms of binary value manipulation, various situations can arise and stress processing tasks that require mandatory performance to be complied too. The performance criteria can be satisfied in general but there are also cases and contexts that stand out as exceptions which cannot be performed. The analysis of such contexts and cases consists of a process for qualitative and quantitative evaluation of the elements that can be measured in terms of performance. Not to be ambiguous, I mention that the performance of data communications is only numerical processing and communication values between two entities in relation to the time required to perform these two generic tasks.

From the data communication/time ratio, there can be shown that there is a need to transmit packets as a volume in the shortest possible time. The analysis of these intervals comprises an interdependence of components with various actions of transmission. Actions between components are performed as a result of an algorithm instruction that regulates the communication between real-time processes. All these actions are called interactions and they are a way of recognizing a phenomenon that has its effect operated in the real-time¹ of a transmission, all in all being the result of the action of one or more components and the reactions that can occur due to unit (per component) or complete system limits. In the context of persistent communications interactions occur very often and are frequent during the selection of routes through self-adjusting parameters and routing equipment of networks and systems.

The understanding of actions and reactions through interactions can be deduced with dependencies. I found dependencies between multiple levels of the OSI model during my documentation period in which I analyzed bibliographic elements with a focus on persistent routing issues that do not have a logical theoretical formulation. This is necessary to facilitate the understanding on how persistent routing works and its internals. For this reason, we chose the methodology of formalizing the concept of interaction for communications with current operating times, actions with effects that are unanimously called global and as being performed in real time [DAR10]. The concept that I defined in order to clarify the dependencies between limits contains parameters and network phenomena that take place at the OSI session level. In order to distinguish between the current time and the variable operating times of data transmissions, I mention that real-time is a notion that recognizes the transmission of packets in current time. The delay times of these transmissions have no way of being known previously because data is communicated through multi-variable media and unlike the field of telecommunications or electronics, the predefining of networks does not require that the data be communicated within the exact limit of a specified time.

The most important thing to keep in mind for real-time routed data packets is that their actual communication time is the one established by the protocol that in turn acts in agreement with the routers and network switches. This cooperation establishes the efficiency for using available resources from the environment. In this way, data packets are transmitted without any obligation to respect time limits that do not have an autonomous protocol analysis as basis, but simply respect the dynamic conditions of the

¹ Notion of informal description for the communication that takes place in the current moments of time on each router participating in the transmission.

routing environment. The transmission actions are self-adapted to the qualitative requirements of the OSI session level technology that is used [BAU04].

The concept of interaction is a methodology for abstracting and recognizing the actions that take place in the functioning of communication technology complexities in real-time. In this manner the transposition of Interaction as a concept into the OSI model through persistent session level routing becomes concrete due to the functional performance analyzes that are found throughout the document.

I mention that the main proposals of this thesis are a synchronization algorithm and a concept through which I formalized the analysis of interactions in and between networks. These have the role of improving the operation of real-time transmissions and to integrate interactions in data environments thus representing a contribution through which we highlighted the applicative role of the synchronization algorithm. All these things are shown in this document in deductible form and explained concisely and as it can be read in the following chapters, the objectives proposed in this thesis have proposed solutions that can be seen as being in line with global research trends.

Persistent routing is a phenomenon that generates a communication route through designated segments and is allocated between two entities to transmit data in real-time. This type of route is created through the communication media in order to be kept in an active state as long as it is needed by the transmission computational process. Because the designated route may comprise network segments that cross networks, subnets, domains and systems, its performance is variable. These performances indicate properties that may be affected by external factors of the communication path [TAN04a], highlighting elements that can act on the transmission and which can disrupt the communication process, in the meantime showing the causes that make the problem of forced transmission interruption visible.

1.1 Objectives

In order to solve the malfunctions of real-time communications, we have set a series of objectives that are presented in the following list. These are the steps that were performed to validate the study's contributions.

- 1) Defining a logical operation plan for communications with an immediate action, plan that has also the role of formalizing the communication rules which create a communication protocol for OSI real-time sessions;
- 2) Carrying out a correct functional analysis, in which to present and describe the hardware and software elements route persistently data of real-time processes;
- 3) Carrying out a probabilistic analysis on session communication time frames, with inclusion of unitary analysis of equipment, as well as complete analysis of structures which are comprised of multiple interconnected devices, networks and subnets to transmit data to a process with current actions;
- 4) Establish performance criteria through which network disruptive effects can be mitigated for real-time transmissions via persistent routes;
- 5) The creation of a synchronization algorithm to reorient the transmission of persistent routes of sessions while ensuring the routing process with near real-time values of computer networks;
- 6) Theoretical formulation of the Interaction concept as being integrated in the OSI model with the role of justifying the actions that happen between the technologies of the transport and session levels of the OSI model through performance metrics and parameters that are related to real-time communications;
- 7) Identification of limits and technical possibilities that could reside / exist in the developed contributions;

- 8) Description of future research directions that could complete this study, the contributions claimed here being based on the existing technological support of the real world;

The mentioned points are how I structured the study and how I managed to develop solutions based on performance criteria of communications with actions in current moments of time, every stage completing the documentation, analysis and experimentation that was performed.

Criteria for establishing and operating real-time sessions that are transmitted via persistent routes are defined by formalized performance metrics through quantifications of time. All the time-based notions we have chosen in this study are necessary to analyze the performances of OSI based session processes. These allow the mathematical formulation of physical and logical capacities for communications while providing the ability to structure the logical steps in order to describe the algorithms through which real-time communication networks are defined.

Criteria are mandatory for establishing routes and these are dedicated to the analysis of initial performance with a minimum level through which persistent routing can work. In this work, the most important ones are the following:

- a) analysis of the transmission capacity of networks through which data will pass in near real-time intervals (immediate);
- b) analysis of communication times according to UTC time zones because the mechanisms through which data are transmitted over networks require an optimal timing for data packet flows;
- c) analysis of the continuous availability to transmit data in real-time through networks;

These objectives are the main criteria by which persistent routes are generated. If the available bandwidth is sufficient and information traffic is driven by fragmentation and priority allocation mechanisms, the continuous data transmission represents the critical point of the problem.

1.2 The Problem of Real-Time Communication through Persistent Routes

This problem can be identified through the method that persistent routes make use of network equipment and environments while being recorded as events, which indicate the existence of unique points that can be error and failure prone. Errors and faults that may occur due to such unique elements are very complex [BHA14] and their need to be understood is pointed out below along with the description of the reasons for their occurrence.

- Network flooding: a phenomenon that can occur when network equipment is flooded with invalid data packets. These packets have header markings as structural requirements which do not lead to a correct destination and are generally of very high volume, beyond the processing capacity of routers or switches. The header of these types of packets require the receiving equipment to transmit or process their contents, often requesting sites that result in network loops which tend to overload the electronic communication medium;
- Stateless routing: this is another communication phenomenon through which real-time session packets are transmitted over various routes without having a direction and state because router's routing tables and switches do not have sufficient information on the active network nodes at the time of the decision in question. In essence, such a case is due to defects in infrastructure that may contain equipment through which the routing pool cannot work properly. In [IOA11] such a phenomenon is described by the blocking probability of routing equipment P_B , in which the formed logical graphs are affected by the lack of arcs defined for the transmission topology;
- Denial of Service (DoS): This is a phenomenon in which certain IP addresses or network regions are targeted in order to cause an *overload* on the network devices. DoS has some resemblance to flooding because it predominantly uses invalid packets, but in general unlike the first point, DoS

attacks have fixed and clearly set targets which cannot be found in network flooding. The header of each packet that's part of a DoS attack contains the target address to which each data packet is to be forwarded, and the DoS datagrams can be both TCP and UDP. Those in the network flooding category are only UDP because only this type of datagram involves a direct dependence on the dynamic routing environment (each packet is passed from router to router based on the decision made by the current router);

- De-synchronization: in desynchronization the problems that may occur have disruptive actions on everything that means real-time data transmission. This phenomenon involves lagging the communication time windows, parameters from which cancellation of data packets that do not meet the requirements of protocol negotiation (handshaking) can result. Desynchronization is identified in the media as a disruptive reaction to systems, perturbing the global uniformity of NTP time. NTP represents a quantification of time by using error margins to account for differences in accuracy between computer clocks that are connected to the Internet and networks. Other examples of adverse effects that may result from exploitation of NTP can be found in the form of time deficiencies like lag in communication framework (jitter)² or blocking algorithmic linkages in operating system mechanisms that process real-time data. The outcome of such exploits can be distorted images and sounds in the case of broadcasts or lack of understanding between parties in case of an IP phone conversation (VoIP);

In the scientific world branch that's dedicated to data communication it has been recognized that real-time transmissions are highly dependent on user demands from applications and programs which use persistence in ensuring the technical performance of computational processes. The reason for which persistence was chosen as a routing phenomenon to perform the functioning of such processes with immediate effects³ is the complexity of routing dynamics. In [LAZ84] the routing cost and traffic cost is represented through the understanding that if certain network nodes and communication segments can maintain a communication flow in current time intervals without traffic fluctuations, it is not necessary to change the communication route. In [TAN04a] the probability of switching or routing to other paths is defined by the update cost of routing tables. This process carries the computation time required to perform the criteria analysis for protocols operation through which uniform continuity between end nodes is sustained.

1.3 Real-Time Process Analysis of OSI Sessions

Persistent routing was originally described in telecommunications, where the transmission process is guided by the open communication channel and kept active throughout its required time [TAN04a]. In data environments however, network segments that are allocated priorly to the actual transmission are the components which act on the whole process. These are currently chosen as being unique real-time transmissions and in this way, in case of equipment disturbances(which transmit the in-cause data) that make the connection to be forcibly stopped, the communication problem of persistent routing is indicated.

Any data traffic analysis imposes a cost that is expressed in routing time. This cost is mathematically described in relations (1) and (2) and complemented by figure 1.1 which is needed to represent the quantification method of the calculation time per routing process. In the definitions of formulas (1) and (2), the authors from [IOA11] performed studies that represent the possibility of

² Action which may cause an erroneous reception of data packets from information flow assemblies.

³ By developers of communication technologies.

numerically mapping values of waiting, residence and transmission times, to numerical ranges with performance limits.

Definition 1.3.1: $\mathbf{A}_0(\mathbf{T})$ is a quantity for an entire chain of events. $\mathbf{E}[\tau]$ represents the average of random variables that must be subjected to performance analysis and through which the actual data packets must be processed in the registration stages as a task $\mathbf{N}_a(\mathbf{t})$, and then served $\mathbf{S}_0(\mathbf{t})$ having time frame limits \mathbf{dt} .

$$A_o(t) = \frac{dS_o(t)}{dt} = \frac{dN_a(t)}{dt} \cdot E[\tau] \quad (1)$$

Definition 1.3.2: arrival rate $\lambda(\mathbf{T})$ involves various pre-processing's of recording times as tasks $\mathbf{N}_a(\mathbf{t})$ and arrivals $\mathbf{E}[\lambda(\mathbf{T})]$ to be set as an average $\mathbf{E}[\mathbf{A}_0(\mathbf{T})]$, so that the routing time(routing cost) can be managed.

$$E[A_o(t)] = E\left[\frac{dN_a(t)}{dt}\right] \cdot E[\tau] = E[\lambda(t)] \cdot e[\tau] \quad (2)$$

In relation (1) the traffic intensity $\mathbf{A}_0(\mathbf{T})$ that is defined by the authors from [IOA11], is a quantity by which an entire chain of events can be analyzed. $\mathbf{E}[\tau]$ represents the average of random variables that must be subjected to performance analysis and through which the actual data packets must be processed in the registration stages as a task $\mathbf{N}_a(\mathbf{t})$ and then served $\mathbf{S}_0(\mathbf{t})$ having time frame limits \mathbf{dt} . This traffic cost is completed in relation (2) with the use of the arrival rate $\lambda(\mathbf{T})$ and involves various pre-processing's of recording times as tasks $\mathbf{N}_a(\mathbf{t})$ and arrivals $\mathbf{E}[\lambda(\mathbf{T})]$ to be set as an average $\mathbf{E}[\mathbf{A}_0(\mathbf{T})]$ so that the routing time(routing cost) can be managed.

The routing cost and update cost are defined by graph theory, and through the means that represent transmissions according to topology structures in which network equipment is located as it performs the information flow. That is why I mention that the sum of arcs⁴ is beneficial for the allocation of a communication route because the distances that need to be covered, are evaluated in terms of network transmission time.

The relations presented in the previous paragraphs are related to a multitude of criteria that are necessary for the process of choosing the best decision on the communication route that is to be selected.

The analysis of workloads for data transmissions related to persistent routing is dependent on an optimal decision-making, which requires an increased focus on each network component from a functional point of view. I have represented this decisional logic in a gradual way, as having determinants that have the following decision-making characteristics:

- 1) listing of available segments from the communication media through which persistent routing connections can be created;
- 2) performance measurement and verification, a method that includes the amount of data from which packets are composed, the number of hops performed from equipment to equipment in the network and subnet transmissions, data transmission speed in terms of available bandwidth and existing time as being recorded on the network versus time UTC;
- 3) comparison of the available performances with the criteria needed to establish the persistent routing connection and choosing the afferent transmission segments;
- 4) request for communication channels and priority services to establish and generate the connection;

⁴ Conventional name from graph theory.

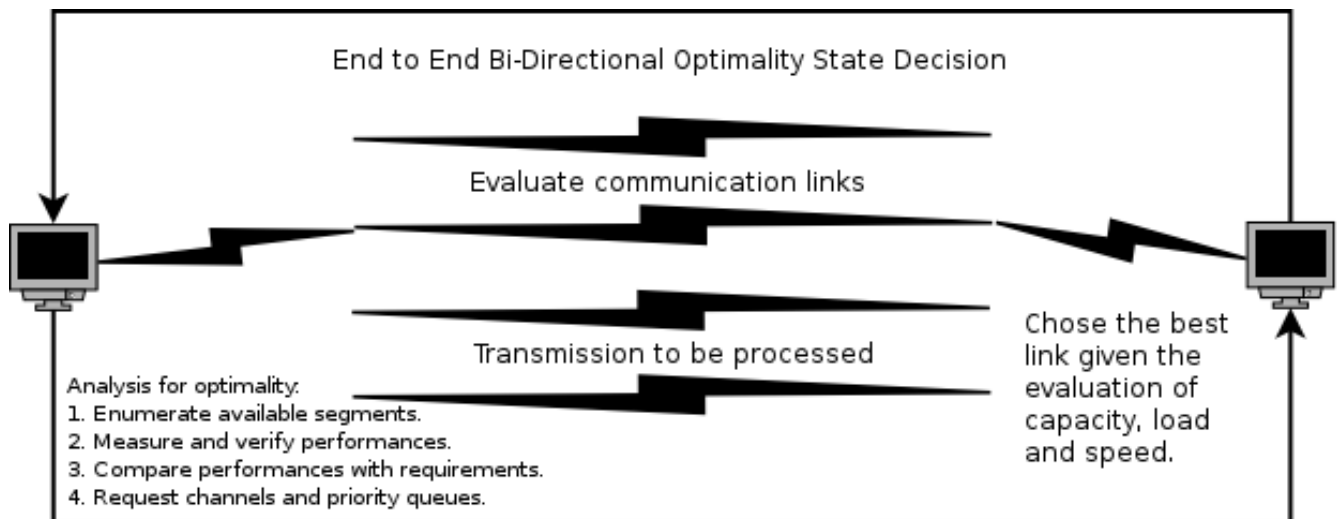


Figure 1.1 Decision-making analysis of communication channels [ORZ14a]

From an application point of view, persistent routing is favored as an action in computer networks by priority and control over transmissions of other types of protocols [BEH89].

The four points I listed above have been defined in order to introduce a note that transmissions happening in current intervals through extended geographical regions require a formalization of functions that are applied at the protocol level. In the formulas and defined relations from Chapter II these functions are defined based on studies conducted by the authors from [TAN04a], [TAN04b], [LAZ84], [BOL06], [IOA11], [IOA08] and others, while the decision support is illustrated to highlight the possibility of simplifying and reducing the vast range of technology to the computational problem.

Introductory Chapter Conclusions

Chapter I covers the introductory notes on the issue of persistent routing and briefly describes the proposed solutions of this thesis. In the previous sections, the set of accomplishable objectives of this thesis were presented with brief mentions to contexts and cases through which the problem of interrupting real-time communications can occur. The general points, essential to any QoS data transmission, are defined mathematically as the cost of routing traffic and the cost of updating routing tables. By deriving from these networking time costs, I created the routing patch choice and faults analysis for OSI session level transmissions.

II. STATE OF THE ART RESEARCH

In this chapter we present the sustaining elements that helped in composing this study. The elements, reference points and afferent knowledge, support the contributions that have been created in order to complete the real-time communication technologies and features. In essence, an analysis was performed on existing technologies and theory from the vast study field that covers computer networks, these being the starting points for existing research approaches.

The scientific world of computer networks has managed to enable and meet a multitude of criteria for requirements that underly various aspects on how real-time processes work [BUR97], but when it comes to reliable communications with continuous availability and fault tolerance, there's a significant shortage of methods which should ensure the proper functioning of related processes.

In this study, the possibility for tolerating intermediate failures that may occur in persistent route transmissions was developed while being mainly focused on what can be achieved by adjusting the performance parameters of the equipment that enables real-time processes.

Routing equipment holds a central role in information transmissions, and it imposes the use of minimum and maximum limits that shape the communicated data volume through the information media.

The simplest way to represent data communications is provided by the ratio between the transmitted bits per time-frame and the given value stands as basis for the entire development in data communications.

Real-time communications is a separate field, which depends on much more sophisticated and demanding criteria than regular or normal internet and network transmissions [CAM06]. All this is because the mechanisms of the protocols considered common, have no time limits for transmitting data, and all research in their direction has been aimed at providing performance that does not disturb users of network services. However, in real-time things are much more complex, because the data that is transmitted between two entities in real-time must reach their destination within a time limit that is set priorly by the protocol that connects the requesters of such a process.

Persistent routing is defined as a problem because it's a network phenomenon that implies a directly generated process which in turn can be affected by overloaded networks that have the timely delivery possibilities reduced, as stated in [TAN04a].

Bandwidth does not impose difficult problems in the world of data transmission, but factors that lead to overloading network segments are critical issues where network availability, robustness and reliability are assigned as properties, as it can also be identified in [TAN04b].

Due to the vast number of elements that form real-time communications, the functional chaining of various stages and thresholds(from one level of OSI communication to another) requires the association of indices and parameters to help formalize the analysis of communication performance. In [LAZ84] these metrics are defined by their importance in streamlining data packet transmissions, having a key role in optimizing communication processes. In the following enumeration I present the in-cause metrics together with their brief description, these being the basis for the developed solutions that are claimed in this thesis.

- C = Servers capacity to take over tasks;
- λ = Arrival rate of workloads to servers for processing;
- r = Waiting time for tasks which are in processing centers;
- R = Response time for tasks that are being processed;
- T = Time to complete the processing of tasks that reside in processing centers;
- U = Usage degree of processing centers in relation to the arrival rate of workloads;
- S = Processing time of the computing station;

- X = The volume of tasks processed in the entire point-to-point communication process;
- D = Volume of tasks/loads that are dropped due to network anomalies;

Optimizing real-time communications requires a concise knowledge of the various causes and problems that can occur in the interconnection of large data networks, and for the processes of real-time sessions, numerous research studies have been undertaken⁵ such as [ARF14], [BAR14], [DAR10] and [HIR10].

Generally, real-time transmissions are presented by researchers as functional, but current studies have shown that a viable way to assign routing possibilities and choices are lacking fault tolerance. Most proposed solutions are slight improvements of existing technologies, these being presented in the state of the art research stage of this thesis.

Since each contribution that is claimed in this study has the role of completing the field of computer networks, I will present in the following paragraphs which is the level at which my personal contribution is suitable to the real-time transmissions that are organized by the OSI model(tab.2.1) ruleset.

The OSI model is the basic theoretical formulation of any communication network which is defined correctly and is also conformant to ISO standards. For defined networks that use the OSI model rules, there are some specified criteria which need to be met, all this being imposed in order to achieve the goal set by the creators of the infrastructure in question.

Currently, the most intensely researched criteria are fault tolerance and reliability, properties derived from the availability of resources, the robustness of programs that form communication protocols and the integrity of information that is communicated through composite environments [BAU07].

In table no. 2.1, a comparison between the classic model of open systems interconnection and the OSI model that is complemented with the proposed Interaction Layer is presented. The Interaction Layer is considered as being an improvement because the logic of the original OSI needs a more thorough grasp on the requirements of newly developed technologies.

In essence, this additional layer is a methodology through which I propose the analysis of the interactions between equipment and network protocols that act as an autonomous assembly with the role of achieving certain performances. The signals and the network equipment forwarded traffic lead to global network and system functionalities, and the numerous actions and reactions of the existing assemblies from interconnected global structures, are dependent on the performances of existing devices and environments.

As an example of the multitude of interactions that can exist in real-time communication processes, I mention the waiting times of data packets in session-level transmissions that terminate a faulty connection. In connection-oriented communications, data packets must be acknowledged by routers that transmit them and by the computers that are the transmitters and receivers of the in-cause packet.

Data packet verification and control algorithms require routers to store data in their memory until they receive acknowledgments of their receipt from the points to which they were transmitted. If a router is overloaded and cannot send session packet confirmation messages in a timely manner (fig. 2.1), the equipment that waits for an acknowledgement can retransmit the in-cause packet/s and wait again for acknowledgments, or it can actually give up on all unconfirmed packets and discard them from memory.

⁵ Study in which robustness has been demonstrated for these types of communications.

The Classic Open Systems Interconnection Model	Complete Open Systems Interconnection Model
Notes on the operation of each level in the model	Mentions about the benefits of completing the model
Application	Application
Provides high-level access mechanisms and protocols for users, ensuring the operation of applications through networks based on Internet Protocol addresses.	Allows the abstraction of resource requests, which are transparent for users of computing technology.
Presentation	Presentation
Implemented to facilitate the process of data transmission between computing systems that use different data representation methods.	Makes communication possible by using various data representations in a computational platform that understands the application of the communication protocol.
Session	Session
Create administration possibilities and a semi-dialogue between remote points in the network, ensuring a functional software system design.	The analysis of the implemented protocol through commands that facilitate its diagnosis is supported.
-----	INTERACTION
-----	It requires an analysis and diagnosis of the technical operational state of a network, and completes the other logical levels through methods and mechanisms of control over dependencies, these being critical aspects in ensuring the optimal operation and the correct use of network resources.
Transport	Transport
Fragments the data and ensures its transmission. At this level there are also protocols for directing and organizing traffic from very wide environments, with a very big data volume and a complex degree of connectivity.	Implements the rules of the proposed communication protocol for data transmission over extended networks.
Network	Network
Assigns network addresses and also ensures the higher levels of the correct configuration of layers 1 and 2.	Ensures the allocation of arguments depending on the active network identifiers and enables the management of those identifiers in the software platform created by the proposed protocol.
Data Link	Data Link
Ensures the correctness of the physical implementation through an electronic connection between devices. At this level, hardware coded addresses (eg MAC, IMEI) are recorded in the logs of the equipment that will support the other levels of communication.	Supports communication protocols and software interfaces with efficient and correct logical implementation.
Physical	Physical
Ensures proper implementation of hardware and physical connections (ex. ethernet and/or optical fiber, wireless, satellite, coaxial cabled, etc.).	Allocates physical resources for data transmission and computation with related technical limitations.

Table 2.1 Proposal to integrate the concept of Interaction into the OSI model as a Layer

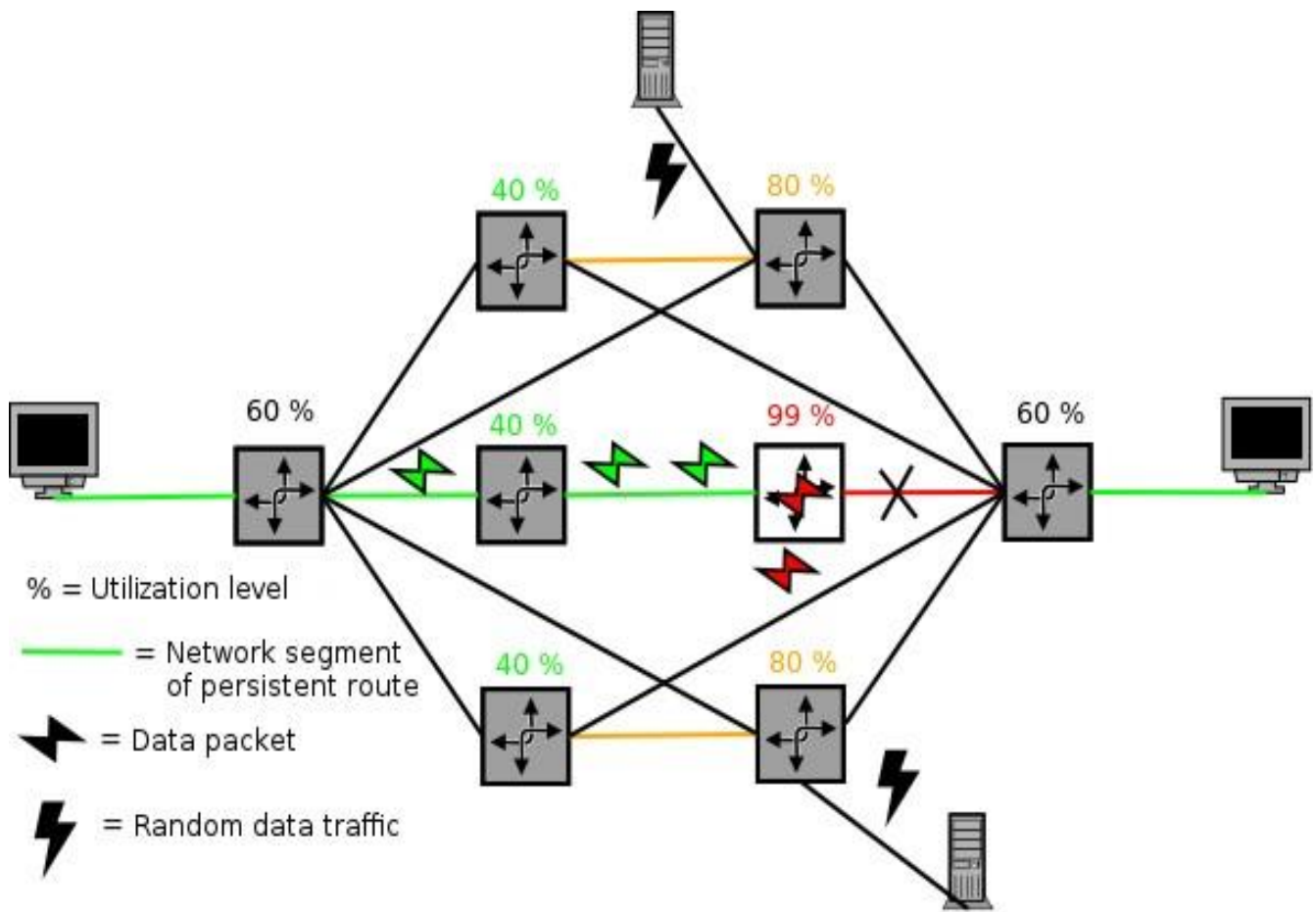


Figure 2.1 Network overload



Figure 2.2 Transmission elements [LAZ84]

I analyzed delay times and faulty communications that cancel real-time performance processes because through these parameters I was able to present the upper usage limits of networking equipment, as well as the lower limits that still allow a correct operation. These are described in the scientific literature by correlating the performance metrics from [LAZ84] with instances of communication timeframes through which data packets are sent, synchronized with routers, acknowledged by routers, and received at the destination. In the figures 2.2 and 2.3, a formal example that confirms this mention is presented, highlighting the need to fragment data communications in order to comply with resource availability as specified in fig. 2.4 [LAZ84]. Each component of fig. 2.2 and fig. 2.3 is represented as having performance limits from the transmission time point of view, and in this way the phenomenon of uniform transmission can take place. The upper load limit in the figures is W , and the maximum capacity that can be reached for each processing center is $W-1$ without blocking states. For all QoS transmission

protocols that require a correct sampling of communication times, this method for setting resource limits needs to be applied generically, in order to prevent race conditions of tasks and to avoid delays and communication lag.

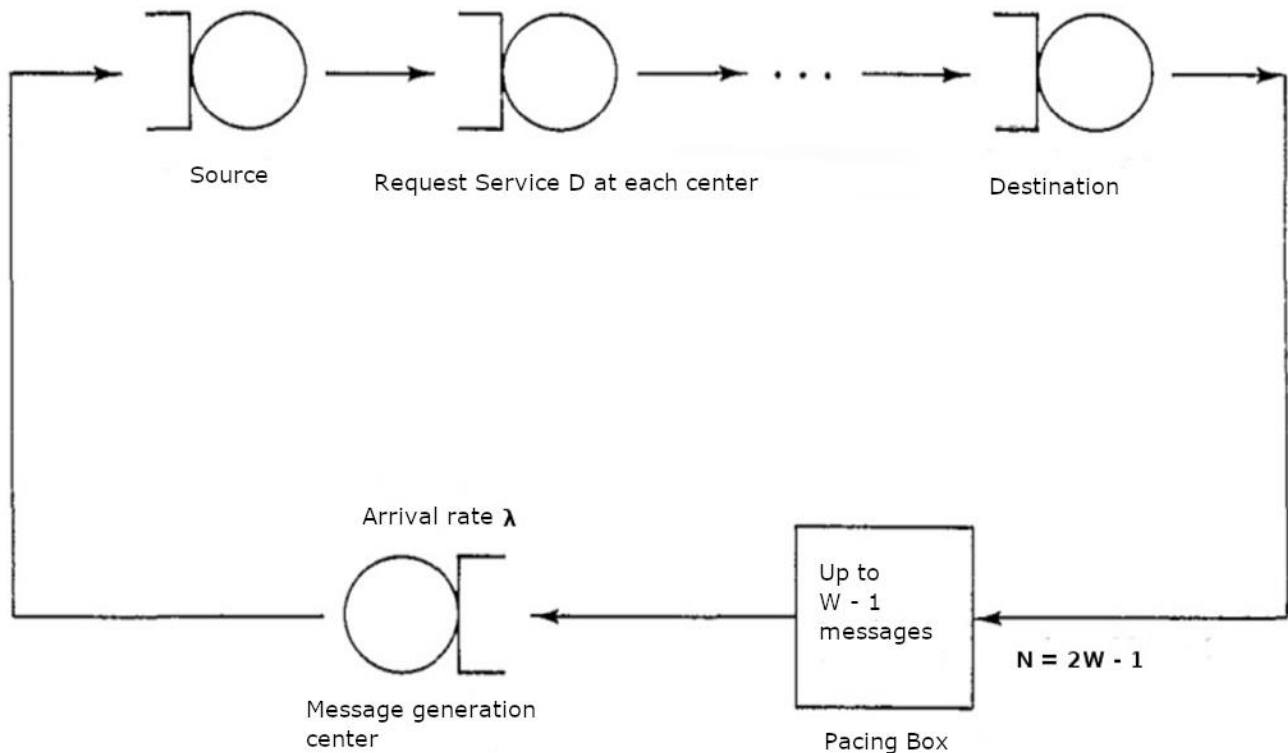


Figure 2.3 Communication window in modeling transmissions with time-based execution steps [LAZ84]

λ represents the arrival rate of the data packets and in the work of [LAZ84] is considered as being a defining metric for controlling data traffic. Notion **D** indicates the point of request for forwarding data packets in a system, while the source and destination hosts are the endpoints for which a data transmission is initiated, executed and completed.

These notions are a small example of the functionality from fig. 2.2, where a data distribution process is represented as a whole that comprises finite processing elements. The notion specification that gives meaning and states capacity limits are presented in the following listing according to their importance in data communication processes. These are the following:

- a) N : Number of messages;
- b) W : Time window defined as a delay value unit;
- c) $W-1$: Ability to process data that falls within the defined time window;
- d) $2W-1$: The maximum number of messages that can be stationary at the data traffic timing unit, these being ordered by the metric unit of the time window;
- e) λ : the arrival rate of client tasks at the processing/generation center in the system;

In [IOA11], the performance criteria are defined because of the need to optimize communication processes in a gradual way for both switching and routing technologies. This distinction is made, as data communications are characterized from a functional perspective, while the two methods of transmission indicate that the process can be executed as a network phenomenon.

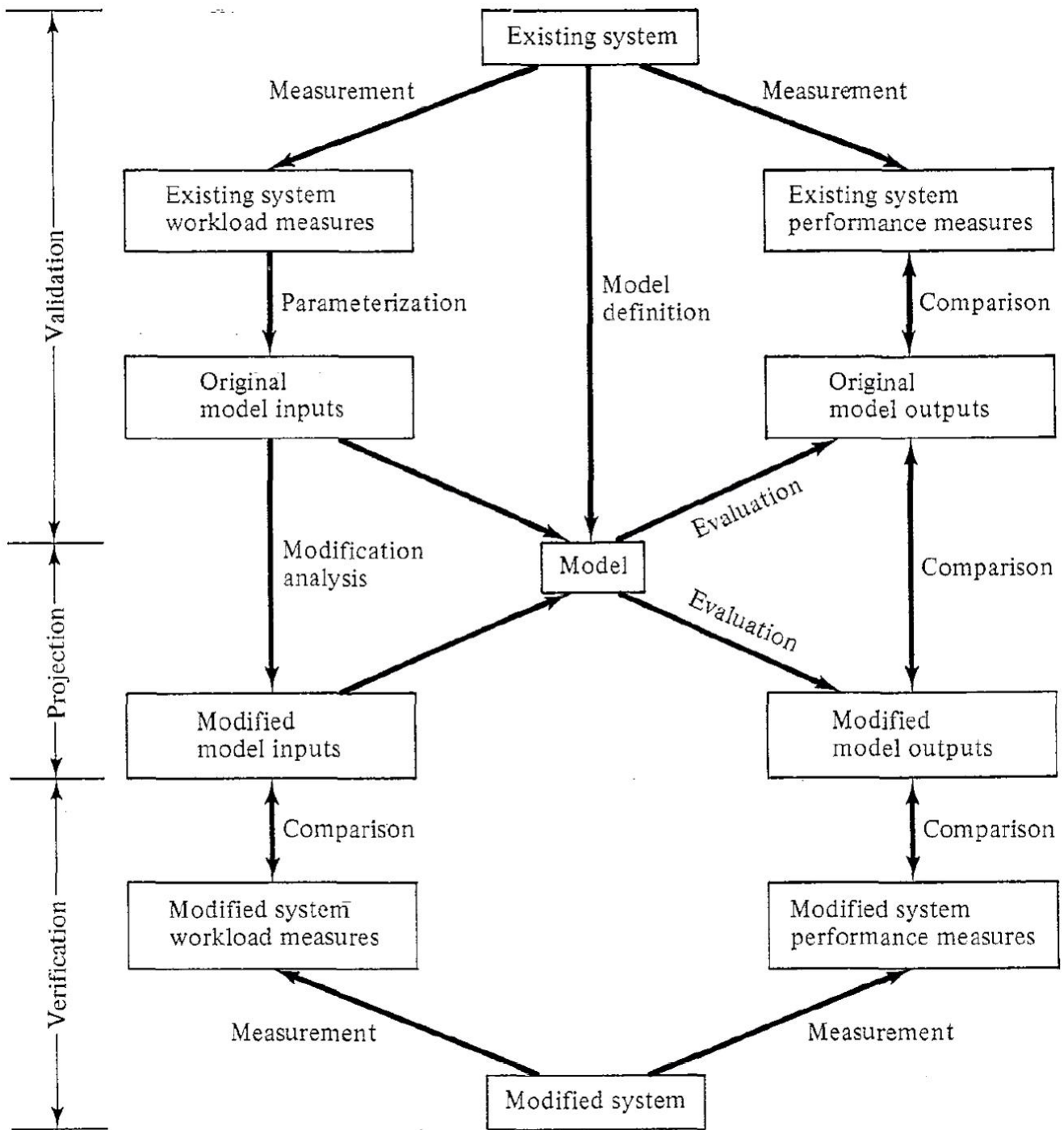


Figure 2.4 Specification for the availability of resources in a system [LAZ84]

In figure 2.5 the performance analysis metrics defined by the authors of [IOA11] are presented as a flowchart sustained by the work of [LAZ84], because we consider it necessary to detail the high-performance network transmissions that underly the personal contributions that are presented throughout the thesis. The metrics are pointed out with a brief description and their role in the theoretical and applicable formulation of algorithms, while performance based flows are explained in the following paragraphs.

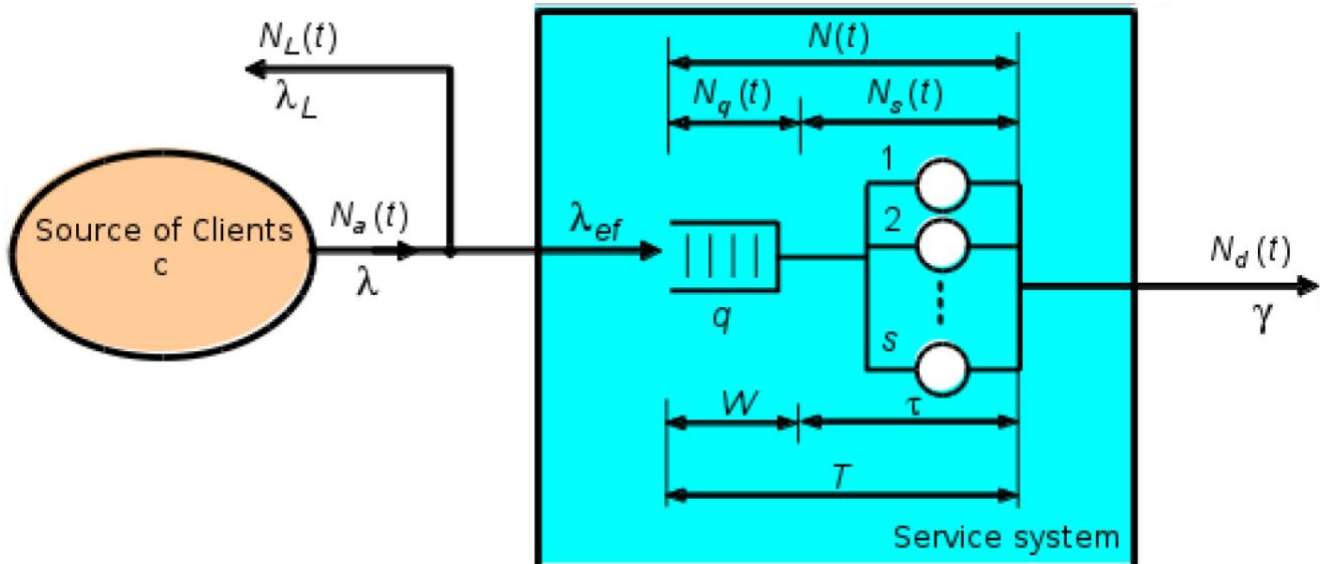


Figure 2.5 Special performance criteria and metrics [IOA11]

- $N_a(t)$ = random process corresponding to the number of clients generated by the source(which arrive at the entrance of the service center);
- $N_d(t)$ = random process corresponding to the number of customers leaving the service system;
- $N_L(t)$ = random process corresponding to the number of customers rejected by the service system;
- λ = the rate at which the external source provides requests;
- λ_{ef} = the effective rate of requests entering the system;
- λ_L = rejection rate(loss rate) of requests;
- γ = the departure rate of requests that have been accepted and served in the system, also called the system productivity. $\gamma = \lambda_{ef}$ and all customers entering the system end up as being completed at some point;
- $N_q(t)$ = random process corresponding to the number of requests that are waiting in a queue of maximum length q ;
- $N_s(t)$ = random process corresponding to the number of requests that are in service, in the “s” servers of the system;
- $N(t)$ = random process corresponding to the total number of requests that are present in the system(in service or on hold);
- W = random variable that represents the queued waiting time;
- τ = random variable that represents the actual service time;
- T = random variable that represents the total time spent by a client in the system, also called system delay time or transit/stationary time while passing through the system;

The source for generating the transmission requests and the communication environment are the two main components through which I studied real – time processes. This is because any element that can be measured as a unit or as a system component (in terms of processing capacity), facilitates the partial or global analysis of the transit/propagation processes through the environment. I mention the propagation or transition of data packets because the transmission of data packets through networks takes place from the moment of generating the data in the form of network requests, and until the packets are confirmed as being received. In this way, the fragmentation of the arrival rate λ in defined time-frames $N_a(t)$, helps real-time routes in the allocation of paths and network segments which in turn meet the required quality requirements through global specifications of OSI sessions.

At the same time, with the fragmentation of the service request times into frames, the waiting and residence times from routing and switching units are also specified. These are noted in fig.2.5 as being

$N_q(\mathbf{T})$ and $N_s(\mathbf{T})$, and with search algorithms from routing tables, these metrics are evaluated and organized hierarchically in interconnected networks. The analysis completion in processing units is given by the correctly routed data packets that are included in a real-time process and which are also acknowledged.

In the following formulas the mathematical evaluation of the relations between $N_q(\mathbf{T})$ and $N_s(\mathbf{T})$ is presented, because through γ (node/routing system productivity), the correct and complete processing of network nodes and distribution centers is described. This metric is considered in the undertaken study as the guarantee and correct operation of the solutions I claim. The metric's implicit validity for productivity γ , can be given by the packet loss rate λ_L and the utilization degree \mathbf{g} that is represented in formulas (3) and (4) respectively.

Definition 2.1: λ_L is the arrival rate for lost data packets that is dependent on the λ arrival rate of requests and the currently blocked requests \mathbf{B} that can be found in state \mathbf{a} (arrived) and which wait for the packets found in service state \mathbf{s} .

$$\lambda_L = \lambda \cdot B(\mathbf{a}, \mathbf{s}) \quad (3)$$

The loss rate λ_L is defined in [IOA11] as a calculation with closely related dependencies between the arrival rate λ at the processing station and the blocked tasks \mathbf{B} that are pending in state \mathbf{a} and are in service state \mathbf{s} . The usage degree \mathbf{g} on the other hand is a relation between the processing tasks rate λ_{ef} and the complete processing time $\mathbf{E}[\tau]$ which is relative to one second of processing time.

Definition 2.2: \mathbf{g} is the utilization degree that can be obtained as a product from the effective arrival rate λ_{ef} and the complete processing time $\mathbf{E}[\tau]$ reported to 1 second.

$$\mathbf{g} = \lambda_{ef} \cdot \mathbf{E}[\tau]/s \quad (4)$$

From the applications loss rate λ_L it can be deduced that the upper(maximum) limit of requests that can be timed is reached in transmission centers and by the utilization degree \mathbf{g} , the number of requests that can be processed can also be mapped in specified time-frames. Due to the possibilities of highlighting interdependencies between various components and sub-assemblies found in various processing states, the productivity γ stands as the number of transmissions that are completely processed by the analyzed system or subsystem. This mention is sustained by the authors of [IOA11] in (5) which states that the number of requests present in the system is proportional to the transit time of the requests accepted in the system.

Definition 2.3: $\mathbf{E}[N]$ stands for the number of requests present in the system, being a product of the effective arrival rate λ_{ef} and $\mathbf{E}[T]$, the time to register requests in the system.

$$\mathbf{E}[N] = \lambda_{ef} \cdot \mathbf{E}[T] \quad (5)$$

Routing possibilities can limit data traffic to canceled transmissions, which consist of packets that are not forwarded to their intended entities. In real-time communications, logical routes are created to be used by the in-cause process. Because of this fact, such a chained event performs the continuous use in a persistent manner of the same equipment and routing segments [LUP04].

$$f_X(x) = \frac{dF_X(x)}{dx} \quad (6)$$

Definition 2.4: $f_x(\mathbf{x})$ is the probability that a point x can be found in vicinity of a node if it is obtained as a report between the density of criteria guided points $dF_x(\mathbf{x})$ and the uniform time delivery dx .

Relation (6) represents the density probability as a random variable \mathbf{X} which appears in the vicinity of a point x found in the system with the purpose to describe the criteria whereby uniformity can be achieved in terms of communication time. In relation (4) the average waiting time is defined as a means to measure the waiting period, being a way through which routing equipment can orient the choice on communication paths in terms of maximum waiting times that are set as a limit in QoS environments.

The utilization degree from relation (4) is mainly defined as a function of performance measurement because it can provide indications regarding the correct application of some protocols and hierarchies of network nodes, while relation (5) is beneficial for defining the data traffic intensity and its timing.

Generally, these relations are characteristic to the calculation of reliability and the afferent metrics [BUR97] that are described mathematically through relation (7).

$$R(t) = \Pr[\text{TTF} > t] = 1 - \Pr[\text{TTF} \leq t] = 1 - F_{\text{TTF}}(t) \quad (7)$$

In relation (7), the notations are represented as being concise units for a temporal evaluation of functionality. The notions are explained in the following points as being:

- $R(t)$ = reliability in a defined time frame;
- $\Pr[\text{TTF} > t]$ = high probability of failure;
- $1 - \Pr[\text{TTF} \leq t]$ = minimum probability of failure;
- $F_{\text{TTF}}(t)$ = time to failure;

Definition 2.5: $\mathbf{R}(t)$ is a results of the probable time to failure $\mathbf{Pr}[\text{TTF}]$ that's greater than time quanta t , which in turn is calculated as a complete runtime $\mathbf{1}$ from which $\mathbf{Pr}[\text{TTF}]$ is subtracted if it is lower or equal to specific time quanta t . This gives the direct dependency of $\mathbf{1} - F_{\text{TTF}}(t)$, $F_{\text{TTF}}(t)$ being the Failure in time t that can occur based on the time to failure TTF , when subtracted from the complete runtime $\mathbf{1}$ of the unit/system.

Being characterized as a continuous flow on a single allocated route in time and space, persistent routing is dependent on the intermediate routing contexts it transits [MAC14]. These contexts are either predefined flows by the topologies through which the data is transmitted, or are routing policies that are represented as initial partitions of the traversed systems [TAN04a]. The contexts through which the form and volume of data traffic are described in routing systems are of dynamic order [MAE10], with the goal of acting on the performance of the transmitted data of persistent routing [IOA11]. In the following two sub-points I present these contexts with a brief and concise description on how they work.

- a) dynamic topologies: through which the data flow is physically and logically directed, having a collaboration that is directly tied to the communication rules of the network transmission protocol;
- b) flow management policies: in which the volume of data traffic is adjusted through an in-between relation of the communication protocol rules;

I mention that the data flow of a route is directly linked with the number of tasks recorded in the transmission network, and formulas (8) and (9) show the related dependencies between the notations and the technical parameters mentioned in section 1.1. These networking operations act as distributions of packets(aggregated data packets that follow a statistical evolution of events) for persistent routes.

$$N = \frac{X}{R} \quad (8)$$

$$U = X * S \quad (9)$$

In formula (8), X is defined as a notation for throughput, N represents the number of tasks and R is the response time [LAZ84]. In (9), U is considered to be the notation that represents the utilization degree for resources, X is the throughput (volume of data successfully processed), and S represents the service time for a processing station [LAZ84]. The links between the relations presented till now are given by the need to perform generic or more fine grained calculations for the usage limits g/U , arrival rates λ/N and the processing productivity γ/X . This common side is essentially a performance analysis for data packets that require guaranteed quality and need to be transmitted at optimal communication times without being disrupted by network blocking actions.

Definition 2.6: N is the result of the division of throughput X and response time R .

Definition 2.7: U is the product of the direct relation between throughput X and service time S .

Data communications are probabilistically modeled by computational laws that are proved to be realistic in expressing the runtime of workload [MUS04]. Little's law is one of these laws and is the most concise method for expressing the operation limits in a simplistic and abstract system.

Little's law (fig.2.6) is a timing application for the desired traffic model [MUR10] and is also an example of the possibility for reducing the persistent routing problem to its defining elements. We used this theoretical foundation in the present study in a concise manner, focusing on understanding the actions of transmission phenomena. The metrics through which this law makes the performance analysis and modeling possible are as follows:

- $n(t)$: number of requests found in the system at time t ;
- T : time frame;
- $A(T)$: array of $n(t)$ framed in the period T ;
- $N(T)$: number of arrivals in period T ;

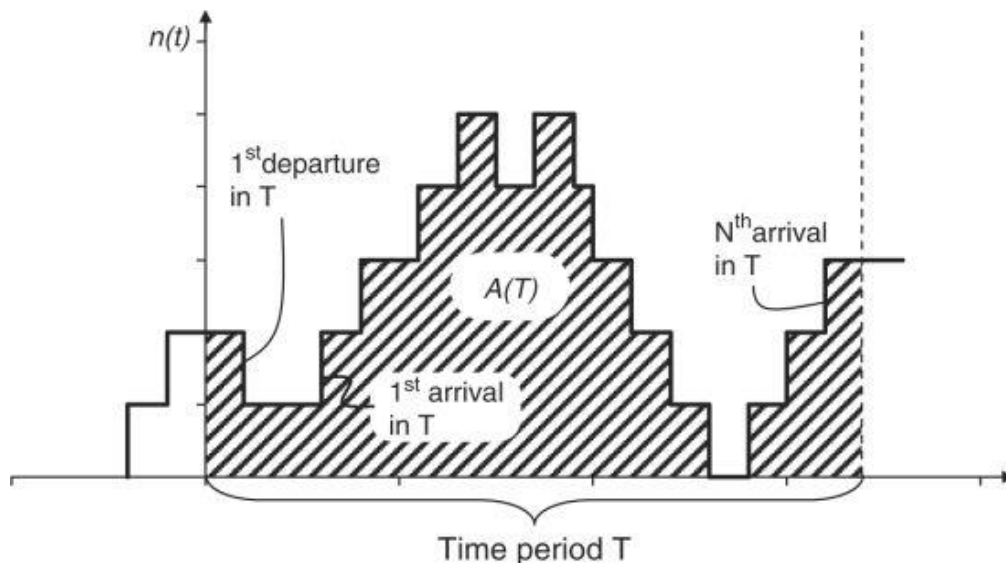


Figure 2.6 Little's Law [CHH08]

A transmission based on time limits is a facility through which communication guidance becomes more efficient [ARF14]. In essence, the partitioning of data packets in the traffic supported by interconnected networks requires the recording of contact intervals with destinations along with the routing segments intervals. With this mention I state that any decision on the means of communication is taken after a preliminary enumeration, as illustrated in fig. 1.1. The enumeration of timed transmission routes is made based on the recognition of routing pools and technical performance parameters by which the relations between networks, subnets and systems are defined in order to formalize the transmission process [MUR10].

The metrics listed at the beginning of the chapter and which are pointed out below, $N_a(\mathbf{T})$, $N_d(\mathbf{T})$, $N_L(\mathbf{T})$, $N_q(\mathbf{T})$, $N_s(\mathbf{T})$ and $N(\mathbf{t})$, are illustrated in figure 2.6 because through them the end-to-end communication process is taken into consideration, process that can be part of a multitude of interconnected communication networks and equipment. Each network and subsystem that performs the data transitions of a real-time process can have its limits [ARY11], thus I mention that a global real-time process(endpoint to endpoint) must be flexible enough at the protocol level to work with the media from a quality point of view.

- $N_a(\mathbf{t})$ = random process corresponding to the number of clients generated by the source(which arrive at the entrance of the service system);
- $N_d(\mathbf{t})$ = random process corresponding to the number of requests leaving the service system;
- $N_L(\mathbf{t})$ = random process corresponding to the number of requests rejected by the service system;
- $N_q(\mathbf{t})$ = random process corresponding to the number of requests found in the waiting queue of maximum length q ;
- $N_s(\mathbf{t})$ = random process corresponding to the number of requests found in service, in the “s” system servers;

Network equipment can be disturbed because of the emergence of negative actions that overload them with requests(denial of service), de-synchronize internal hardware clocks(stratum inaccuracy) and last but not least, exploit the signals of communication agreements(handshakes) [TAN04a]. At electronic level, the transmission capacity is defined by the bandwidth and speed of the data transmission[CHA14], but this can be variable because the propagation environment is sometimes limited by interfaces that cannot provide a processing that is as fast as the dispersion of signals through the physical environment [BAR14].

During the transition through persistent routes, data packets transit through various forms that have different values given by the traversed/crossed networks. The values in question are in turn given by the mechanisms which fall in the following operation categories:

- a) broadcasting by unicast direction(streaming);
- b) directing data flows according to the time window;
- c) step - by - step assignment(pacing);
- d) verification and control of data packet acknowledgements;

Point "b" presents in most cases communications that are affected by factors such as large volume of data, necessary to be processed and communication software errors (fig.2.7).

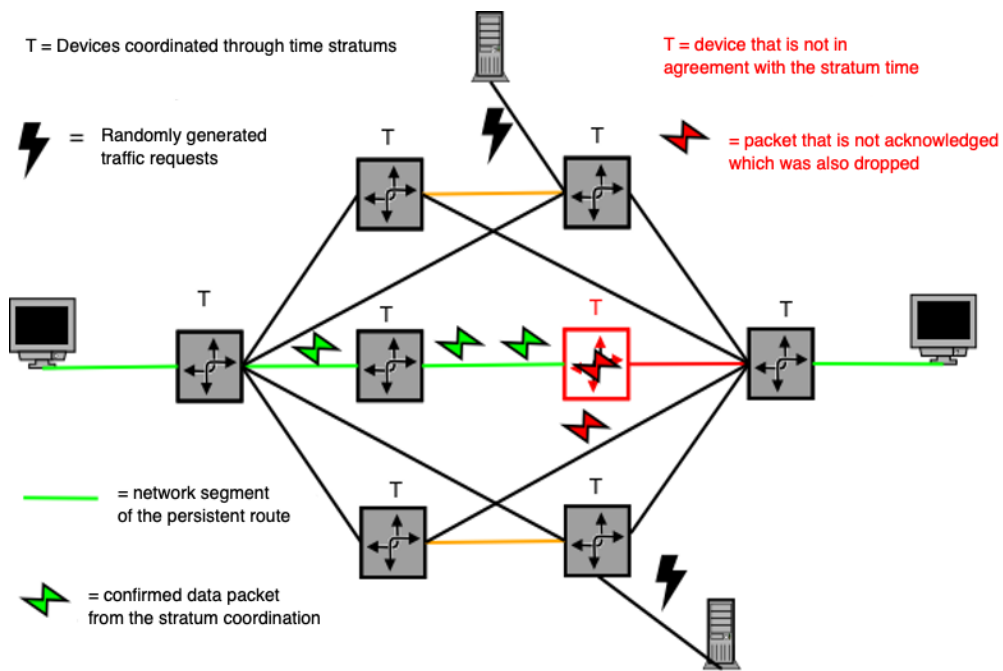


Figure 2.7 Utilization of transmission equipment

In fig. 2.7 the load degree is illustrated fictively because the presentation of the error context is necessary for the understanding on how the communication problem can occur. A routing issue for real-time sessions may occur due to a faulty or overloaded router, which in turn is a coordinator for data traffic that's afferent to the real-time session.

There are many dysfunctions that can disrupt the operation of persistent routes through which session data is transmitted in real time, these having various methods for acting on real-time processes. In the performed documentation process, I've distinguished a multitude of negative effects that can disrupt these demanding transmissions from a qualitative point of view [BOL14]. In general, the negative effects result from parameters that are based on time quantification, especially for equipment that does not fall within the upper and lower limits of synchronization for end-to-end communications [CSE10].

In the figure 2.8, the incorrect synchronization of some network equipment is represented, a problem that leads to a global error for the real-time transmission coordination. This malfunction is due to the fact that the requirement to certify the legitimacy of data packets is incorrectly applied, resulting in a cancellation effect of transmitted data packets. Another thing that can happen, is the meaningless transmission of data packets to other network routers, with the hope to find a router that can confirm the correct structure of data packets.

In the mentioned relations from the previous paragraphs, the authors of [BUR97] have defined a means to assess the capacity of routers in terms of quality requirements. I need to mention that based on the existing modeling from relation (11), the reorientation of real-time transmissions that is proposed in this thesis as a solution to intermediate network faults, is fully applicable as it will be presented in the following chapters.

At times when data packets are not transmitted in optimal intervals, a multitude of blocking actions that affect persistent routes take place [CUI12]. These blocking actions have as a theoretical explanation the incoherent access to the memories of communication equipment [DAL01], the latter not being able to execute the instructions of the real-time protocols in the necessary time intervals that are set as criteria by the performance metrics. Communication times facilitate the creation of time windows to streamline the flow of information through networks [DUO12] and in real-time sessions these space propagation windows are the continuous chaining of data packets.

In the studies undertaken by various authors such as [TAN04a], [THE14], [DAR10] and [FAT14], various notations are used to express the usage of time as a finite interval in the transmission of amounts of information through routing media. Throughout this document, a multitude of notions are presented and each variation or resemblance will be pointed out to emphasize the context in which they were introduced.

The synchronization algorithm which is proposed by this thesis is the application of a temporal evaluation by which the chosen transmission paths are considered as the best decisions to continue a real-time process in active state.

Network equipment synchronization is applied worldwide and generally UTC standardizations allow a realistic approach to handling time interval indices from data packets. What has not been considered so far in the case of real-time sessions traversed routes is that the fault tolerance of a disturbance from a segment that's performing the transmission can be achieved by transmitting data on a segment capable to take over the initial transmission and which at the same time respects the criteria to transmit the information of the decommissioned segment. To highlight this fact, in the following paragraphs the composition of the designed algorithm is presented in order to establish the continuous transmission performance of persistent routes, a component that operates from the perspective of three main indices that we have defined, namely \mathbf{T} , \mathbf{t} and \mathbf{t}' .

An allocated time \mathbf{T} is considered a starting point for data packets from source to destination. In communications between two entities this time \mathbf{T} is unique for both entity 1 and entity 2 because real-time telephony, video and data transmissions can be from both participants of the communication process at the same time⁶. A time limit allocation \mathbf{t} follows, limit in which the actual time to transmit the data from one point to another is framed while the time unit \mathbf{t}' includes the time required to communicate on alternative routes, data that can only be transmitted during a normal operation time limit \mathbf{t} . These notions are presented in the following listing, because they are used in this document to describe the various stages of communication performances for processes that apply the proposed solutions:

- 1) \mathbf{T} = global time for entities participating in the real-time communication process;
- 2) \mathbf{t} = time required to transmit data between the entities participating in the communication process;
- 3) \mathbf{t}' = time required to transmit data from the transmission process on an alternate route;

Performances based on time are a part of the characteristics of the developed synchronization algorithm along with the condition that these need to be satisfied by the devices that will act when failures appear in real-time communications. Routers and switches run in accordance with the rules of the communication protocol by which the data is guided on different routes, and together with the technology types they represent a whole of information that is part of the communication process. The proposed algorithm acts at the routing logic level of the OSI model and for fault tolerance, I will mention gradually the protocol operation mode in the following listing.

⁶ I mention "at the same time", because the communication of information is perceptible for real-time application users as taking place at the same time, but due to the ability to transmit data quickly with the use of multiplexing, this process takes place by communicating data in unique time quantities for an entity that is part of the real-time electronic process.

- 1) step 1: the network faulty router or region is identified by the remaining active devices(those found in the vicinity of the defective equipment) of the real-time communication process;
- 2) step 2: the parametric data of the real-time communication process is consulted by the remaining active routers;
- 3) step 3: the parameters necessary for real-time communication for an alternative route are set(time t' defined between two approximate limits);
- 4) step 4: the neighboring active routers are listed by the router found still in operation, the prior hop to the faulty equipment;
- 5) step 5: the pre-fail node router communicates to the neighboring routers the request to find a path to the subnet or the destination end point of the communication process, provided that the route to be selected respects the required performance criteria, namely time t' ;
- 6) step 6: if multiple positive responses from routers are received, the next step proceeds with choosing the router that corresponds most optimally with the criteria of correct communication time usage and most correct operational usage history;
- 7) step 7: the data is communicated to the router which can provide the necessary time t' to be contained in the T global time necessary for a real-time communication between the endpoints of the persistent route;
- 8) step 8: endpoints confirm the receipt of data packets and continue transmitting without interrupting the communication process;

Real-time communication protocols of the OSI session layer are considered from the design stages [BOC80] as having a minimum requirement of resources to transmit data. In this manner, T global time and interval t can be obtained from the technical specifications of protocols. The problem given by persistent routing (fig.2.9) has time t' as a resolution for communication conflicts in routing. This is because that although a segment can be out of order, or even entire networking regions that include classes of IP addresses and subnets that can be decommissioned, there are alternative routes that fall in the limits of t' .

Time frames measured and incorporated in the transmission process, allow via the averages of transmission units the observation of the logical coordination from transmission equipment [CIA11] which is more difficult to achieve due to the complex functional dynamics from computer networks that are capable of real-time communications.

The claimed proposals of this thesis, the synchronization algorithm and the interaction concept, are two solutions that can be implemented by protocol communication rules. Any communication protocol requires optimal algorithmic coordinated agreements that are beneficial for a good data flow through interconnected media [CON14], and for real-time transmissions, the procedure for tolerating faults that I created is embedded in the protocol logic from fig.2.10.

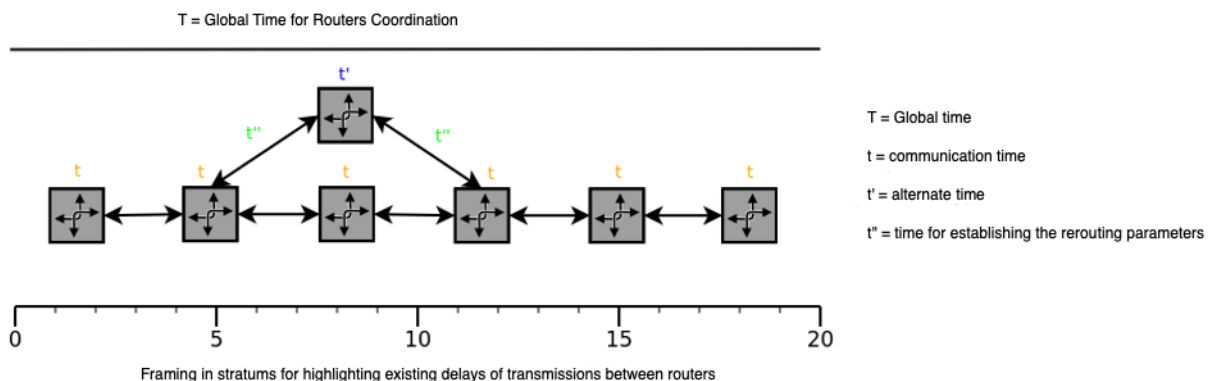


Figure 2.9 Mapping time requirements

The notions from figure 2.10 are defined in order to present the essential points of the selection process of an alternative route through which fault tolerance of real-time sessions may occur. These are very closely linked in terms of data packet parameters and because networks generally function, the problem is given by the possibility of the networking environment to sustain multiple transmissions with a high degree of qualitative criteria.

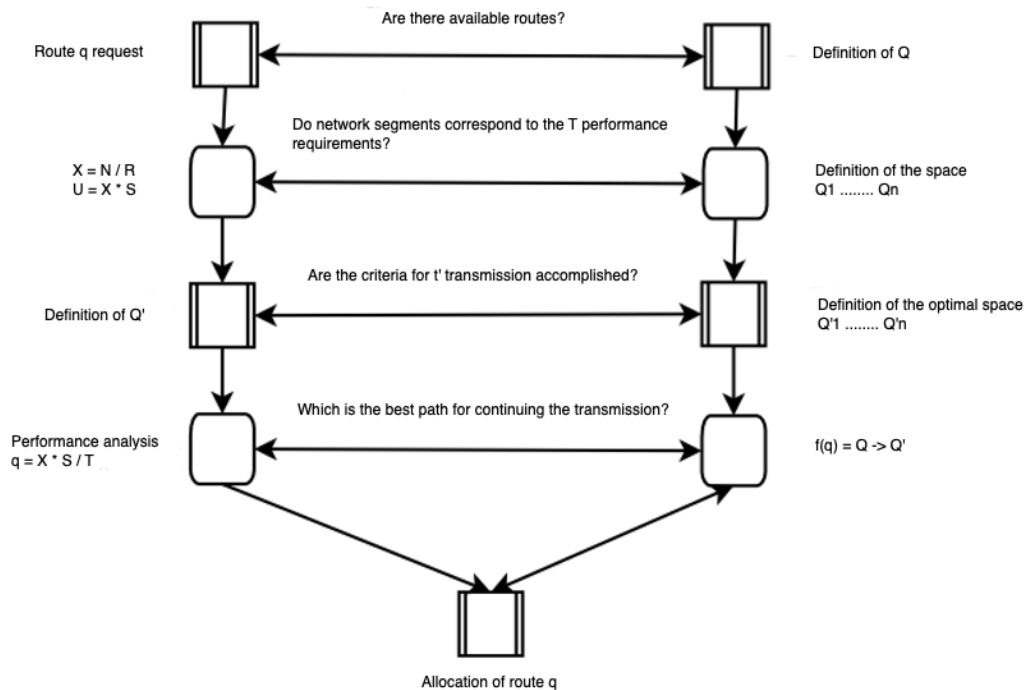


Figure 2.10 Protocol logic with functional dependencies

The TTLs, TCP sequences, time windows and checksums are represented in the diagram from fig. 2.10 in the form of a relation $\mathbf{X} = \mathbf{N}/\mathbf{R}$, where the indices are logical correspondents to the operation of the computational assembly. The assembly functions as an analysis through which performance is parametrically adjusted at the equipment level, the latter being a component part of a multi-device cooperation that's guided by the real-time communication protocol of the session layer. I mentioned this because not all sessions have a real-time runtime. Depending on the type of application(ex. broadcasts, multicast and control terminals), various mechanisms such as character type devices [TAN04a] and those of type intermediate memory block, are allocated for protocols that can trigger the data packets of communication sessions with high waiting time.

Alternative routes are selected to continue an affected transmission on certain network segments. This is the main validation method of the proposed solution. As communication routes exist as being available in various intermediate networks, through these routes data packets can be transmitted by the persistent routing protocol. To be taken into account, is that the alternative route to be chosen(the one that complies with the allocation criteria \mathbf{t}') role is to perform the immediate continuous operation of the transmission process.

Routers have a multitude of ways to allocate alternative segments but in the process of allocating a communication that will include \mathbf{t}' , this allocation is made following an autonomous decision taken by the network based on the parameters of the communication protocol. Thus, the entire process of

allocating alternate segments will include the number of existing segments of the router that's adjacent to the affected one, plus the first neighbors of that router.

The definition of the selection range is given by the fact that the topologies, functions and protocols for renewing routing tables are implemented to make the choice of shortest paths from extended networks, a mode of operation that's in-expendable to Internet traffic [DAL01].

I will continue with the presentation of the selection process for route ranges that can be considered as alternative segments. When renewing routing tables, data traffic management equipment provides a new index with all the existing segments that are active. This index contains the number of routes that can be selected to forward packets to other devices, routes that can include service types and continuous streams. The results presented in this section are a representation of the synchronization algorithm applied on the simulated routing contexts, contexts in which the obtained performances indicate a degree of reliability that can be assigned to the algorithm.

Mentioned previously, the measurement metrics for waiting times in networks stand as a basis for the developed synchronization algorithm. The algorithm is demonstrated with its usefulness, depending on the defining components of any persistent routing process, namely the network search space and the criteria for allocating a route for a transmission.

In the following notations I present the identification of the two components necessary for the operation of the process, and they are listed because it is necessary to understand the choice of the alternative forwarding route from a multitude of alternative routes that are available.

- a) Q = available route;
- b) $(Q_1 \dots Q_n)$ = the selection space composed of the available routes that can offer the choice of an alternative route which has the corresponding requirements;
- c) $(Q'_1 \dots Q'_n)$ = limited space to allocate a resource after performing the appropriate requirements analysis;
- d) Q' = restricted space for the allocation of a communication route;
- e) q = chosen route;
- f) $f(q) = Q \rightarrow Q' \Rightarrow q$ = route chosen for routing reorientation;

Because the analysis of alternate segments depends on the availability of resources, the definition of routing criteria in the protocol that establishes the agreed upon communication rules is mandatory [EAS11]. From this step, taking into account a search space that includes equipment that's adjacent to disrupted routers is the deductible possibility of continuing the transmission. In defining the search space of links to be chosen are also the fundamentals of dynamic communication from computer networks, which is present due to the logical structure of routers.

Necessary to understand from the measures defined for the identification of methods that will serve as solution in reorienting transmissions, is that the measurement indicts have dependencies between them and these dependencies are in turn formulated to allow the choice of a route q . By using the relations (8) and (9) from [LAZ84], I have defined the choice process of route q from the value pool $Q'_1 \dots Q'_n$, pool that results from the evaluation of the selection space $Q_1 \dots Q_n$. These relations impose the general performance conditions that must be met by the new communication route once the functional process provides numerical runtime indicts that will later be used as a comparison template.

$$N = \frac{X}{R} \quad (8)$$

$$U = X \cdot S \quad (9)$$

The conditions mentioned by the degree of throughput X , together with the use of transmission points U , allow the deduction of the selection space Q' . Given that the component transmission time

must be met as an operating requirement, q is selected after the definition of the criteria from formula (12).

$$q = \frac{X \cdot S}{T} \quad (12)$$

S represents the service time of the work tasks being multiplied by the "throughput degree" X , a divisible product with extra workload time T that results in the identification of the point that can continue the transmission. The point of rerouting is primarily setup with the previous throughput parameters, having a node service time that is within the service limit, and is an optimal choice for transmitting data at time T intervals.

Definition 2.10: q is the results between the product of throughput X and service time S , that's reported to time T .

From the domain literature where I can also give as example [FAR10], two main branches can be distinguished as fundamental research, namely the one focused on the probabilistic mathematics of Markov Chains, and that of linear algorithms from Queuing Theory. In this study I want to present the contributions through the prism of both theoretical formulations in analyzing information flows and I developed the research stages according to the results found in the bibliography.

For a concise understanding of real-time communications, relation (13) simplistically describes real-time transmissions in terms of measured time, a notion which is relevant in determining the communication time of a transmission protocol defined as having real-time actions. The notion of time in data communications is defined as global or individual per equipment and communication segment. This is why I have set time T as the global time, and t as the individual communication time per segment.

$$\sum_{s=1}^n X_s = t_s - 1 = T \quad (13)$$

In relation (13), T represents the overall communication time between endpoints (data transmitters and receivers) of a real-time communication process, and t represents the communication time of each segment s . The summation of communication times forms the process in question, where T is presented as a result because the summed times of each segment with a communication performance t must be limited, and by reducing the amount of time with a quanta "1", a real value is obtained that does not tend towards infinity in a transmission. Noted with X_s is the ability to pass a threshold in a direct relation to global time T , because only the generated packets that meet successfully the performance criteria are taken into account in the calculation of protocol guided transmissions.

Definition 2.11: the summation of all segments throughput X_s is equal to the segment transmission times t_s minus 1, not to tend to infinity.

Real-time transmissions require an increased priority when they are created by communication media, these having as a requirement the fulfillment of two features with high significance. Firstly, real-time communications differ from common Internet transmissions in that they require an optimal correlation of transmission frames from segments, with the general process of connecting directly the transmitter and receiver. This is as natural deduction, that a synchronous algorithmic chaining is absolutely necessary for the fluidization of communications between endpoints [FEA04]. Secondly, communications between endpoint entities require that protocol rules be considered concisely for

session-level transmissions [FOU14]. As a conclusion for the two mentioned functionalities, I mention that the communication rules guide in all aspects the operation of OSI session layer communications in real time.

In the following sub-chapters I will point out these features through the perspective of studies conducted by other researchers, developments that are starting points for research in real-time communications or are manuscripts with insignificant results for the subject of OSI sessions.

This performed study takes into account a lot of arguments and technical statements that I have analyzed from the applicability point of view with real world scenarios, which to my stunning is not considered realistically enough by the addition of confidence factors or probability weights to justify the dynamics of the internet. In this manner, in the following stages of the current state of the art technology level analysis, I will present the technological consideration of the academic world to reliably ensure the availability of computing resources.

Arguments and technical statements given by authors such as [ARF14], [BAR14] and [BYH14] conclude that internet traffic cannot ensure and guarantee real-time communications, a statement that is fair for the technology level that was 20 years ago. At the present time however, methodologies for tuning algorithmic performances of routes show that communication infrastructure may have sufficient resources such as bandwidth and priority slots [YAA14] and the flexibility of transmission protocols form the communication problems themselves.

In [CON14], a study was conducted to indicate the evolution of resource availability over time in transmission infrastructures, a perspective that is rarely considered for routing processes. This is because routing is defined by connection oriented or connectionless communications. Connectionless protocols are proved to be the fastest for cases where network data environments are saturated with resources and do not wage high volumes for processing. The problems that arise become obvious when routing devices loop and drop packets as a response to the lack of information about the recipient of the data packets. On the other hand, connection-oriented communications require routing media to identify the recipient of each data packet for each transmission, even if it is an intermediate destination in the network transit process. From a technical point of view, this methodology is called TCP communication, in which each request has a concrete response from the routers found in the process of connecting two geographically dispersed network hosts, while communications that are based only on momentary decisions of routers, without any defined connection, are called UDP.

Understandable from the proposed solution is that the choice of the segment that will continue the communication between two endpoints is limited to transmitting to a neighboring router(that is not disturbed), the data of the affected segment (fig. 2.11), point from which the routing process can continue to the destination [ORZ14f].

The created algorithm is designed to find an adjacent route that can meet the initial performance requirements of the faulty/overloaded router on the network. For this action to happen, it implies an operation that is given by the use of initial transmission times and the measurement of the adjacent segments response time in order to define the route selection pool. Then, the transmission trip times to the destination are compared with the functional prior time values and the next step in the algorithmic analysis that is performed, namely the comparison of the optimal historical operation between the routers that are adjacent to the defect/offline route. The comparison between routers operations and the adjacent segments is performed by the granular metrics pointed below, these being weighed in order to obtain a uniform routing(without variations) for the persistent route that is to be further operated.

- $N_a(t)$ = random process corresponding to the number of client packets generated by the source(which arrive at the entrance to the service system);
- $N_d(t)$ = random process corresponding to the number of packets leaving the service system;
- $N_L(t)$ = random process corresponding to the number of packets rejected by the service system;
- λ_{ef} = the effective rate of packers entering the system;

- $N_q(t)$ = random process corresponding to the number of queued requests, which are of a maximum length q ;
- $N_s(t)$ = random process corresponding to the number of in service requests, in the “s” system servers;

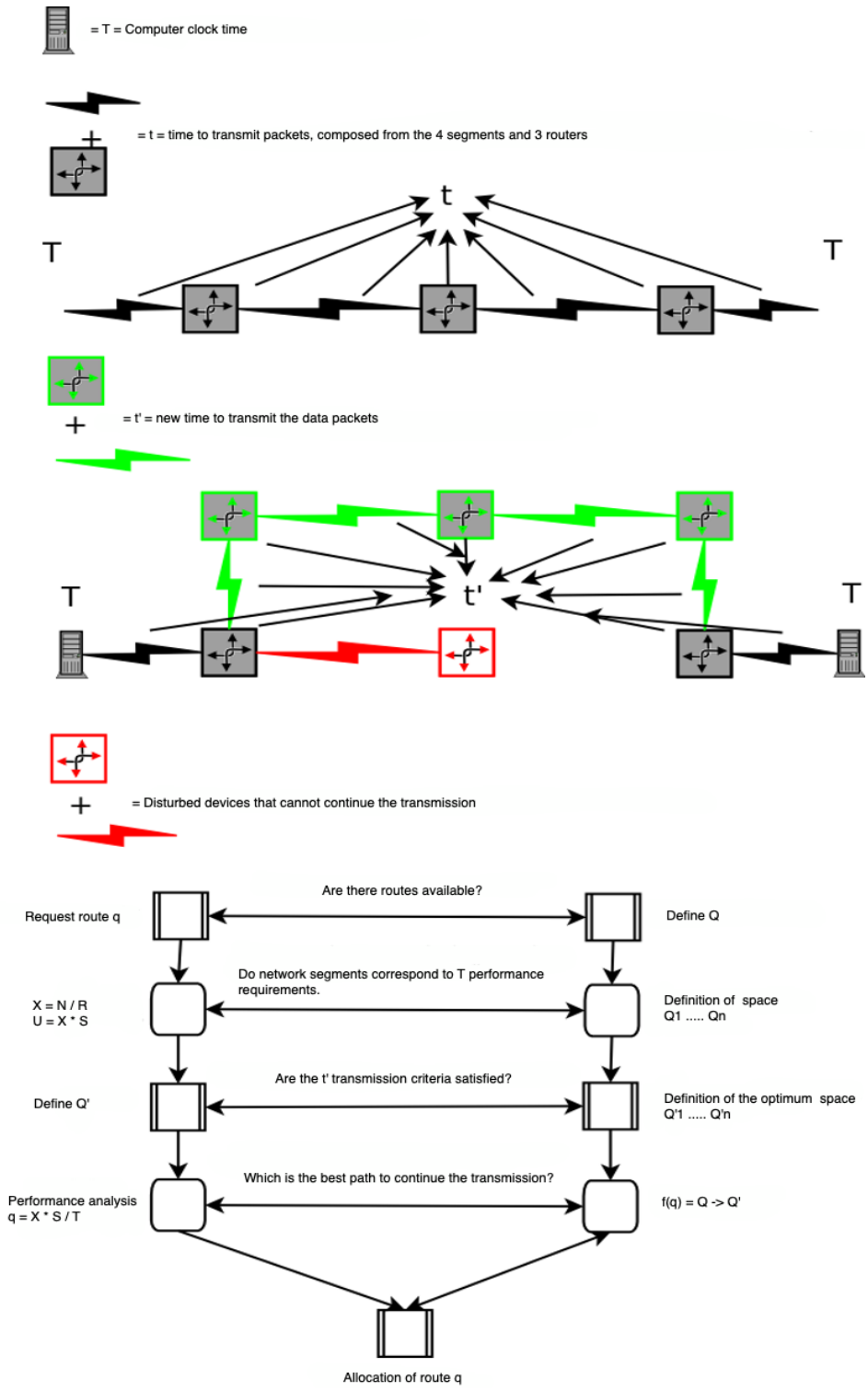


Figure 2.11 Protocol logic for the operation of the synchronization algorithm by analyzing network interactions

The metrics that have the largest weight in the comparison process are $N_q(T)$ and $N_s(T)$, which show the size of the queues and the processing speed of data packets. The calculation in question significantly influences the selection probability of an adjacent network node because it considers the operations that are immediately necessary for continuing the persistent route. All this implies the possibility that adjacent links can enter blocking states as well.

The route reorientation process contains handshakes with neighboring routers [GAO01], which before establishing an agreement need to confirm if they can meet the requirements of a real-time data transmission [FAT14]. The accomplishment of these requirements implies that from the chosen equipment that is set to transmit the priority data, routing is performed persistently on a new path chosen by equipment.

Connection-oriented and connectionless communication processes include technical parameters such as TTL indices, number of network hops and data fragmentation, service type flags, error correction codes, and the sender and recipient network addresses. Being components that create a data packet, which is also named in the scientific literature as an IP packet, they guide the routing process from one routing device to another by providing clues as to what is specifically required from the transmission environment [GAZ10]. The communication processes do not expect a solution that can be acceptable only from the perspective of a set forwarding feature for data packets, and this is due to the fact that both the routing protocol specifies the datagram structure(data packets) that is to be transmitted [HAL08].

Probabilities represent for the process of evaluating systems a complete possibility outcome spectrum method. In this study I chose this evaluation method because through probabilities there is the possibility to determine the performance of dynamic routing cases and contexts. Because the definition of routing space and the assignment of priority values by indexes in routers are of utmost importance for real-time communications, the analysis of all cases that may exist after consulting performance measurements is the method through which an optimal selection can be made.

Conclusions for the State of the Art in General

At the beginning of chapter two we presented the components of the persistent routing problem in a broad manner along with their correlation to the analysis methods and tools that are available. Metrics based on time magnitude are represented in terms of the solutions they propose for the OSI Interaction Concept, and for the synchronization algorithm in the process of rerouting real-time session transmissions.

2.1 Probabilities of Residence Time Values

In this sub-chapter of the current research state I will present data packets latency time in processing devices for the context of persistent real-time routing, because residence intervals are essential for the diagnosis of interactions that may occur in transmission media.

From a metric point of view, downtime can be categorized according to the capacity of each routing equipment, but for a whole/global real-time process that's enabled between distant endpoints, time intervals must be and are generally set according to certain criteria and limits. Residence time limits are part of a special aspect of streamlining communications in real-time and what is desired from them is to be uniform when running this type of communication. In the real world however, existing cases contain variations, and for protocols that connect geographically dispersed endpoints, the operating mechanisms for adaptation and adjustment is partially functional. The property of adaptability has been

considered by many researchers that study real-time data communications. Examples of articles and studies are [HAG13], [HIR10] and [HU13], where these transmission types are presented as variances of TCP handshakes that are unique solutions to minor network disruptions.

The solutions for minor communication disruptions are defined in real-time technology development projects by probabilities and more precisely through the probability that a residence time value will appear at some point with a positive or negative effect. In the following relations from [IOA11], mathematical formulations are represented for the probabilistic calculation of downtime in distribution centers (14), processing centers (15) and routing hosts (16), and next to them is the degree of utilization (17). Through these 4 representations, the valences of residency are associated with the capacity to keep tasks in the memory (processing of packets) of equipment.

$$p_0 = \left(\sum_{j=0}^s \frac{a_j}{j!} \right) \quad (14)$$

Definition 2.1.1: p_0 requires a summation of work tasks j and an initial ratio of task arrival rates a_j , for tasks waiting times to be recorded for processing $j!$.

$$p_j = \frac{a_j^j}{j!} \quad (15)$$

Definition 2.1.2: residence time implies a limited processing power, hence p_j represents the number of tasks from a maximum of tasks that can be taken over a_j^j , in the processing state of a volume $j!$, of data packets arriving at the in-cause router/processing center.

$$a = \lambda/\mu \quad (16)$$

Definition 2.1.3: the tasks that may be in the state of being processed a , is given by the ratio between the arrival rate λ and the service rate⁷ μ that is related to the analyzed network node.

$$g = \lambda_{ef} \frac{E[\tau]}{s} \quad (17)$$

Definition 2.1.4: the effective load rate that's accepted in the routing system/router λ_{ef} involves a correlation of the transition times in the system with the actual service time τ relative to a specified amount of time s . The degree of actual utilization g is obtained to serve as an indicator in accepting data packets for processing.

Being focused on secure transmissions, real-time communications are developed through a prism of optimal coordination of packet data transmissions [HOD08]. The packets are therefore guaranteed by the transmission medium through the form of a quantity of information that's composed by the following attributes:

- a) Data packet source address;
- b) The destination address of the data packet;
- c) The type of service indicated by the data packet;
- d) Data packet time to live;
- e) Data integrity information coordination (ex. padding bits and Hamming codes);
- f) The in-cause transmitted data;

The mentioned attributes are components of data packets that are transmitted in real time, the packets having in the same time a default structure given by the communication protocol and routing

⁷ The service rate is directly affected by the cost of updating routing tables, as well as by the fragmentation and timing threads of the data packet flows.

device. The structure creates through assigned performance indices of communication parameters a transmission rate through which quality characteristics are highlighted for the real-time process [HON12].

The recognition of segment capacity to carry the timed transmission is a determination that permits persistent routing continuity [HU13]. In each route that's passed by real-time sessions [GAZ10] there is a performance from where the logical topology of networks that are built over infrastructure can be deduced.

The number of hops and the time to live of data packets have variable values because the operation of a logical topology generally requires predefined flows. From these facts, centralized networks can be distinguished, networks in which the routing processes are continuously monitored, or they can be observed in a decentralized manner as most logical networks work. In the case of persistent routing, decentralized topologies are the most common, but in a strict and centralized coordination, most applications cannot be integrated into network environments because they are always influenced by certain factors that cannot have their negative effects tolerated/mitigated too much. Possible changes in the topology of centralized communication can bring remedies to disturbances that can be analyzed [ORZ14b], but in no case will such changes be able to have a successful implementation in large traffic networks and the internet.

In the previous paragraph two types of broad topologies were mentioned, topologies through which persistent routing can be implemented with a functionality given either by the application case or by the analyzed context. Transmission timing implies that resource usage improvements are to be made with adjustments between devices, but cannot ensure the operation of routing in a fixed environment without the possibilities of allocating alternative routes to balance the volume of data in network traffic.

In the analysis of the authors from [IOA11], the modeling of transmissions is made through the mathematical expression (18).

Definition 2.1.5: $N_s(\mathbf{T})$ represents the number of served requests and $N_a(\mathbf{T})$ represents the requests arriving in an interval of time \mathbf{t} , having γ as a parameter for the service rate, and λ as a notation for the arrival rate. The expression is considered the normalized throughput processing capacity \mathbf{th} , a facility that correlates optimally with transient states of data packets from various stages of a transmission.

$$\mathbf{th} = \frac{N_s(\mathbf{t})\gamma}{N_a(\mathbf{t})\lambda} = \frac{\gamma}{\lambda} \quad (18)$$

Also from the study conducted by the authors from [IOA11], it can be seen that the current research state also allows a quantitative analysis of data packet losses, calculation that's possible with the use of relation (19).

Definition 2.1.6: λ_L is the loss rate, and $N_L(\mathbf{T})$ is the number of requests rejected in a limited time range \mathbf{t} .

$$\lambda_L = \lim_{\mathbf{t} \rightarrow \infty} \frac{N_L(\mathbf{t})}{\mathbf{t}} \quad (19)$$

In the present study there was the need to represent the real-time communications organization in terms of measurement and control metrics. With the purpose of highlighting the existing transmission problem, in the following sub-chapters I have described other structures and methods for organizing communication networks together with points where persistent routing may be affected by denial of service. They are also directly related to the adjustment of the performance parameters from routers and

switches, having high valences with the fundamental laws of timed data propagation, statement sustained also by [HUR11].

The effective rate of transmission completions for real-time data processes represents the degree of performance of persistent routes, point where communications can be considered as having a degree of trust what can be taken into account for each end to end communication process.

In the conclusions of the authors from [MOD13], the communication rate of data transmissions is analyzed with the purpose to show the possibility of adjusting the volume of information in data packets (fig. 2.12), and starting from this premise, the mechanisms of fragmentation are considered as beneficial for maintaining active states for real-time communication processes [MUD14].

In relation (20) γ represents the productivity of communication networks having the time ratio between the number of in service requests $N_s(T)$ and time t . This relation is one of the common points that need to be reached by real-time communications that must be quantified in well-determined time intervals to process data packets successfully and in the right order.

$$\gamma = \lim_{t \rightarrow \infty} \frac{N_s(t)}{t} \quad (20)$$

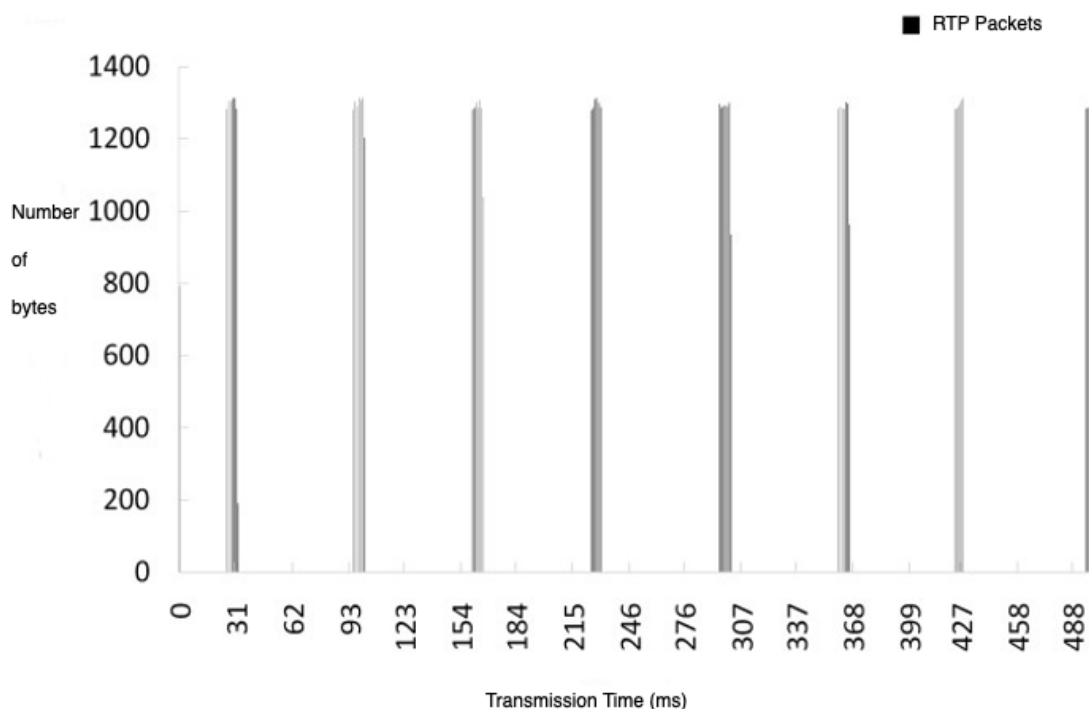


Figure 2.12 Bit/second transmission for real-time data packets [MOD13]

Conclusions for Residence Time Probabilities

In sub-chapter 2.1 the probabilistic methods for evaluating routing actions have been presented and described, these being specified for measurement and quality control purposes of persistently routed data services. Their mathematical formulations from relations (14 - 20) complete the qualitative analysis of real-time sessions because the minimum and maximum limits of hardware resources are managed parametrically in terms of data packets quantity and volume.

2.2 Accuracy of Balanced Network Processing

Balancing communication routes for persistent transmissions is another important characteristic of real-time sessions. In general, network balancing is not a phenomenon that can be achieved exclusively for real-time sessions [NAK14], being moreover an action through which sessions can be provided as functionality.

In the study of bibliographic materials that I performed, I identified that parameters which create data packets provide clues for the formation and fluidization of transmitted data volumes and this process also includes persistent real-time session routes.

In [LAZ84] the authors defined the formulation of network balancing with the usage of wait times and finite processing regions, a methodology that specifies communication time limits as an indicative for allocating other routes in case some are overly demanded. This is a simple formalism, but as an applicability for cases in which complexity is taken into account for vector-based distances, routing is a means through which the quality of transmissions was researched from a structural point of view. This point of view is given by the logical organization of network segments which involves the definition of leveled graphs in large networks, and if one route is more efficient in a distance/time ratio, a disproportion of quantifiable metrics is shown. Routers operate based on data packet variables (TTL fields, service type, data fragmentation, correction codes) and for real-time communications we have identified a variety of methods to route particular data with the use of algorithms that are englobed in protocols. In the following enumeration, these algorithms are presented with their usefulness to define and describe dynamic topologies for extended networks [IOA11].

- 1) Binary Search Trees: binary trees represent for real - time sessions the infrastructural support offered by hybrid communication topologies⁸ in order to optimally allocate the network nodes that will drive the routing process. In the following points I present the most used algorithms for implementing balance in networks, these being created to support quality of service through trust and availability.
 - Best Match Prefix: a search methodology for the tree code prefix of interconnected nodes from networks. This method requires mainly an initial search in the immediate vicinity of the assigned prefix because a prefix justifies the existence of nodes in the immediate vicinity of the in-cause prefix allocation. These may include logical nodes, with routing tables that can resolve the immediate rerouting based on the existing disjoint links of autonomous systems.
 - Compressed Pathways: compressed paths bring multiple benefits in organizing route selections. These allow the narrowing of nodes in routing trees to main nodes (points where the creation of tree branches begins) that serve the communication environment in a more transparent and heterogeneous way. The main advantage for persistent communications is the reduction of traffic and routing table update costs that can be organized in certain regions according to the performances of routers. The performances in question are communicated between the main nodes of the formed logical trees and through this possibility, the allocation of acceptable segments to support real-time transmissions can be performed.
 - Multibit Trees: through multibit trees an effective search method can be created. Such a method allows a route search that can be estimated as an advance response time from routers that perform the analysis of communication routes, and at the same time permit the recording of network positions in a way that can make a probabilistic calculation of the next network hops in terms of downtime.

⁸ In the internet, this type of topology consists from the multitude of classical topologies that are interconnected with each other to fulfill the interconnection process.

2) Time-Based Graphs: time-based graphs are another method for formalizing network actions, method that is mainly aimed to coordinate data packet flows into branches that meet the criteria specified by the networking protocol. In the following points these criteria are described in order to highlight their applicability in the processes of finding communication routes through routing tables that contain quality indices [IOA11].

- Serial: the serial graph creates a chained serial ordering for logical segments, essentially forming a sum of the logical portions that meet the formalized distance criteria. In topological organizations of this kind, there is a high blocking probability P_{Bs} , and this effect is expressed mathematically in relation (21). Relation (21) shows the functional link of network segments for a unitary whole that can be taken out of operation by a volume of data required to be transmitted through outdated environments in terms of the ability to transmit information packets in a timely manner.

$$P_{Bs} = 1 - \prod_{i=1}^L (1 - p_i) = 1 - \prod_{i=1}^L q_i \quad (21)$$

- Parallel: parallelism is yet another possibility for transmitting data over networks, and it is specified in graphs as a way to communicate process data through different segments. In workload terms, transmission segments have fewer data packets to transmit but are requested as a whole. Topologically, parallel segments can be seen as several possibilities to connect two distant entities in which all or a large proportion of the parallel segments are useful to the communication process. The benefit is visible just in certain cases, where the data reaches its destination faster, and as a performance deficit I mention that the use of a large number of paths can also result in high delay times for longer segments. In general, parallelism is necessary for instances in which recipient entities process data almost instantly and do not have to form queues with high residence times. This is represented in relation (22) because in transparent routing centers, parallelization of tasks is also made possible in order to find the optimal routes for nodes that work together at the level of equal performance⁹.

$$P_B = \prod_{i=1}^L p_i \quad (22)$$

- Parallel-Serial: this type of graph is dedicated towards formalizing quality indictors for cases where parallelism is beneficial in a transmission, but needs to be serialized for the communication process in question. From an organizational point of view, data environments present different network phenomena and fluctuations for transmitted data volume,s and through this graph type that's described mathematically in relation (23), the uniformity of communication times in data packets can be adjusted as needed in the network topology;

$$P_{Bp-s} = \prod_{j=1}^M \left(1 - \prod_{i=1}^{L_j} (1 - p_{i,j}) \right) \quad (23)$$

- Serial-Parallel: the serial-parallel graph consists of the definition of units for pre-processing data packets, these being finally transmitted through many network links. Generally, through serial processing regions, specific indices are implied for partitioning the traffic in data environments (24). Applying the operation mode through parallelism

⁹ Equipment of same type and same processing capacity for tasks, applied in order to allocate transmission slots in the best possible time.

provides in turn the ability to transmit data by using multiple intermediate media that do not reduce the whole communication to critical infrastructure points¹⁰.

$$P_{Bs-p} = 1 - \prod_{j=1}^N \left(1 - \prod_{i=1}^{L_j} p_{i,j} \right) \quad (24)$$

Being a method that performs an analysis on the type of transmission from networks, the probabilities of blocking graphs depend mainly on criteria that are defined for creating persistently routed sessions. The criteria have the role to restrict the number of connections that can take over the tasks of sessions and in this manner, it is possible to determine the functioning and timely evolution of performances from logical communication segments.

In general, the topologies used in the Internet are serial-parallel and parallel-serial due to the heterogeneous nature of the Internet to which subnets and subsystems constantly adhere.

Balancing transmission paths has a multitude of logical possibilities to make resource usage more efficient. As such, the properties and methods of organization that have been presented in this sub-chapter need to be known. Each infrastructure network has a topology that started from a few basic properties, but with the increase in the number of nodes that are found in the network, each interconnection with another system(network component of the Internet) imposes certain functions to be met for domain crossings. The solicited requests of guaranteed quality of service (QoS) requests are satisfied by various topology graphs and these can deliver QoS requirements if network resources are used optimally [YEH01].

Research in OSI session communications make use of tree searches, because decision-making logic favors the finding of routes with sufficient resources [ORZ14f]. These are complemented by guidance graphs for persistent routes [GUO12], because the global transmission optimum is always seen as a goal that must be met by the autonomous system through which real-time packets are transmitted. In general, as stated in [BHA13] and [IOA11], protocol data is aggregated and forwarded by prefixing, while protocols that require QoS have the criteria of shortest path(shortest route in distance and time) to be met only if the history of aggregated data is acknowledged as a transmission in the time intervals specified as reference.

Conclusions on Balanced Networking

In subchapter 2.2 the methods for balancing computer networks have been presented with a focus in which data packets of OSI connection-oriented sessions can be transmitted. The types of graphs and route search algorithms are categorized in order to highlight the current trends in routing through interconnected networks, while the mathematical support is defined by blocking actions probabilities.

2.3 Distribution of Quality on Service Routes

The route distribution network action is performed mostly for sessions that are routed persistently also through quality of service. Quality of service(QoS) represents a methods that ensures transmission quality in terms of data integrity and speed of communication. In general, the scientific world has identified the possibility of ensuring resource availability and certain operation limits such as the speed

¹⁰ Bandwidth and finding an optimal route with regard to path length, and last but not least, the transmission lag that's caused by infrastructure policies which norm routing devices.

of network bandwidth as well as the correct functioning of the communication agreements. The possibilities to guarantee quality in transmissions will be presented in this sub-chapter, and these means are based on Markov Chains probabilistic modeling [IOA08].

Modeling through Markov Chains provides a concise methodology of analyzing persistent routes that transmit real-time sessions data, and in the following points various types are presented as computational assemblies.

- M/M/1: a model that provides a simplistic mathematical formalization for data streams that use a single transmission unit. Poisson type processes most often uses this type of modeling because it facilitates an observation that is as accurate as possible for viewing the maximum limit that a service unit can withstand as well as its operation in various stages of use;
- M/M/s/∞/s: through this type, a multitude of metrics are specified that ease the analysis process of network blocking actions. For real-time sessions, this model is necessary and recognized as part of the design of protocols which run in real-time, because quality limits that need to be available are defined by the decisions and logical algorithms of the routing device;
- M/M/s/c/s: the M/M/s/c/s chain of events is essentially an overlay of an existing topology through which the receival and transmission states are defined in order to predefine the blocking limits of the transmission device;
- Geom/Geom/1: an accurate modeling of inputs and outputs from discrete event strings. This organization method has been developed due to the fact that the systems built from a temporal point of view must maintain the communication times of the data packets within imposed time limits, while having as basis Bernoulli's law;

The above presented distribution types are comprised from a wide range of transmission protocols that are applied in infrastructures [PET08]. They are implemented in transmission protocols through parameters and indices which integrate with the construction of data packets. As an example worth mentioning is the TCP package structure which requires a correlation of data fragmentation with bandwidth and device transmission rates. Other types of data packets such as UDP and ICMP also allow the autonomous organization of routing regions, these being in the context of this study adjacent technologies through which the volume of data traffic from the internet is managed.

Conclusions Regarding QoS Distribution

In chapter III, data distributions will be presented more widely through the experiments that have been undertaken in this study. As logical constructions, they highlight the events that appear in data traffic and also show the impact on packet routing with various performance indicators. For real-time sessions, data distributions are analytically modeled in terms of Markovian states and present variations and derived cases where data overloads are mitigated in order to allow the operation of fault tolerance on a single route of persistently transmitted data.

2.4 Adjustable Indices and Parameters for Persistent Routing

In the scientific literature I have identified a multitude of parameters that can be adjusted in order to improve real-time transmission performance. Given that session transmissions contain high quality requirements, the means through which these can be satisfied are provided by the communication media composed from routers and switches in which sophisticated protocols are implemented to perform such

tasks. The analysis of events from transmission moments that are found through distributions which in turn are identified by features and properties, is a good tool for researching the performances of OSI sessions, and these are categorizable by the adjustable parameters from protocols.

A persistent route is characterized as a data transmission logic through a wide environment between two or more entities, having the role to maintain the communication path as active for as long as it is necessary. Its operation is given by the main elements of any data transmission and I will present these elements below, together with the functionality of a persistent route in terms of a computational process:

- a) Request to communicate over a network with a specific entity;
- b) Search for a routing path that can be kept as active for as long as necessary;
- c) Determination of the fundamental elements of network transmission between the entities that participate in the communication process (fragmentation mode of transmitted data, data formats that are supported, data packet transmission speed, algorithm for correcting through a logical level possible transmission errors);
- d) Establishing the communication route and registering it as persistent;
- e) Real-time transmission of data packets via the route created in the system, this being in accordance with the parameters established at point c;
- f) Connection close for the persistent route when there is the need to stop the session-level communication process.

The enumerated steps present an understanding of persistent routes in terms of how these processes can be addressed, and which in the telecommunications domain have been resolved as a communication problem. In telephony systems the process of communication through a persistent route was composed from the identification of the sender and the receiver, the opening of a communication channel through the telephone network, and the closure of the communication channel only when it was necessary.

At the data transmission level, which requires a route to be opened through the transmission networks, persistent routing is dependent on both the sender and the receiver, as well as on the equipment performing logical network functions.

The following paragraphs describes the purpose and adjustment mode of transmission parameters between the transmitter and the receiver of a real-time process.

Upon request to communicate with an entity, the issuer makes a request for creating a real-time transmission and generates a request message that it sends to the routing environment. In this message, which is in itself a data packet, are included the source and destination IPs, the type of service, the number of bits that compose the data to be transmitted in a uniform manner, and the time to live counter.

Elements that form data packets have been specified over the research evolution periods and they are at the moment parameters needed in the description of algorithms that streamline transmissions in infrastructures [TAN04a]. As components of any data packet, they have a certain applicability which I briefly describe in the following listing.

- a) source address: field that must exist in any request data packet, because routers and switches need to know where to send back the requested data;
- b) destination address: the address to which data or data requests will be sent;
- c) time to live: counter which specifies the lifetime in jumps from router to router (only routers specifically assigned are able to change the life counter) of data packets, because an intercepted transmission is not desirable to continue and a connection is canceled if the counter increment is unjustified;
- d) protocol type: the rules specifying whether IP packets are encapsulated, encoded and/or adjusted to be correlated with the times that prescribe an algorithmic mode of operation as uniform as possible with the communication process that's requested by the sender and recipient. Due to the multitude of protocol types, the number of ports (sockets) specified in operating systems (network,

- computer, router, server) was 65535 TCP and 65535 UDP, each port and datagram being associated with a specific protocol or network service that's guided by an appropriate protocol;
- e) checksum: field through which the data bits that are transmitted in the data packet are counted and checked from point to point if they are still the same value throughout the routing process. This parameters specifies a possibility to ensure the integrity of the transmitted data;
 - f) IP packet version: field showing the structuring pattern from the components of an IP packet in bits, the major difference between the two current versions IPv4 and IPv6 where the size of the data packets are of 32 and 128 bits, respectively;
 - g) type of service flag: this option facilitates the process of route allocation for traffic routers and network switches by specifying the type of service and by default, the protocol used by the network devices which firstly consult their assigned local ports to communicate data by type and afterwards routing tables to identify which port is the best route to reach the desired destination;
 - h) the transmitted data: the software address space in which the information to be communicated is encoded for transmission;
 - i) sequence field: the packet number that is part of a transmitted message, this being directly related to the fact that a network message cannot fit in a single data packet;
 - j) additional bits for error correction: information added in the form of surplus to the communicated data. These bits are added at the beginning and at the end of each data packet, and are the most susceptible to loss of one or two bits of information in case of minor disturbance effects on the transmission media. With these bits, that can also be redundantly applied to data packets, routing information and transmitted data can be reconstructed;

Depending on the type of Markovian communication model that exists in networks and/or the type of logical topology(serial, parallel, etc.), the above points are used and help to adjust the operation of OSI sessions through the interconnected data media.

Conclusions for Parametrized Indices

Subchapter 2.4 has had the role of presenting indices and adjustable OSI parameters for real-time session routing. The structure of data packets and their usefulness in QoS requires that the protocol decision logic be well defined for the purpose it must perform in routing. That is why we have briefly described each component in the context of connection-oriented communications.

III. PROPOSED SOLUTIONS

This chapter presents the thesis contributions in more detail, proposed solutions that have been developed to meet the fault tolerance criteria of real-time sessions. The contributions have a broad experimental description that's presented together with comparative statements(strengths and weaknesses) on existing solutions. Briefly mentioned in the introduction, the concept of interaction and the synchronization algorithm are the solutions that are present along with the representation of the communication problem of real-time sessions. Demonstrating the possibilities that are claimed in this study are the simulations that will be presented, these being the means by which the claimed synchronization algorithm and the concept of interaction were developed.

I consider the synchronization algorithm a better solution compared to other studies because it brings a significant improvement in routing. This consists of fault tolerance on a single route without involving doubled or tripled data traffic. Mitigation of intermediate faults through additional data traffic(doubled and/or tripled) involves primarily the transmission of data packets by using additional resources and is often susceptible to data interception attacks.

The time cost for routing a whole process data traffic is lower with the algorithm I propose, because the routes from the adjacent segments are taken into account at the occurrence time of an intermediate defects. This is a feature that is imposed in the algorithm, and it can't be found in any other fault tolerance method for real-time transmissions.

From a logical point of view, the synchronization algorithm is also supported by the interactions analysis which is proposed as theoretical support. Through the theoretical know-how on recognizing network actions and reactions that take place at the transport layer for OSI sessions, the application of the interaction concept facilitates the parametric analysis of the synchronization algorithm and its protocol plan.

In transmission media, time synchronization has the role of highlighting the real-time process, which with proper management of networks requires proper operation. Having time frames measured and embedded in the transmission process, the transmission media allows the observation of the logical coordination of transmission equipment, which in computer networks is more difficult to achieve due to the complex functional dynamics. Through this possibility, the synchronization algorithm also allows a dynamic management of network resources, which is a possibility that does not exist in alternative solutions that tolerate network faults.

By analyzing the availability of resources from adjacent network nodes, it can be seen that there are usually sufficient transmission capacity resources to apply a reorientation mechanism. This statement is sustained by the analysis of capacities from CAIDA's communication infrastructures, and by the presentation of capacities from simulated networks, which through queue theory present the availability of needed resources.

Because fault tolerance in routing of OSI sessions requires a qualitative operation in accordance with the parameters of the communication protocols, I mention that all the performance analysis models I have created, have the role to indicate the usefulness of the proposed synchronization algorithm in adjusting the effects of interactions between components of interconnected networks.

Any component of a data transmission has limits of capacity and reliability that can meet depending on the execution conditions in which it is located. Due to this fact, not only the benefits that can be obtained from the synchronization algorithm are presented, but also the limits at which it falls in.

The adaption of communication parameters is a complex process, and this is because it depends on realizing implicit dynamic data packets markings with special indexes that are set on routers to forward data in certain manners, or to facilitate the processes of transmission reorientation [MAS17].

Real-time session reorientation is also possible due to the fact that it requires a marking of service type fields like Type of Service(ToS) and Quality of Service(QoS) in data packets [YOU11]. Through these attribute fields, network devices can adjust the TTL field of data packets and also use parity, redundancy and control bits to detect and avoid network collisions in order to streamline real-time communications [BID15].

An analysis on the operation of network devices and on the behavior of data flows was performed so that the relation between components which creates real-time processes can be clear and obvious. I have defined relation (25) in order to achieve a uniform time-based classification for packets that are transmitted between adjacent routers and are partially reoriented in a session-level process.

$$\frac{\lambda_{ef} * \tau}{t} \cap \frac{N_q(t)+N_s(t)}{Q'} \rightarrow t' \quad (25)$$

Expression (25) is the mathematical representation of the proposed synchronization algorithm. It is a cooperation of algorithmic embedded rules that could be found in a protocol to reorient packets in routing pools by adjusting parameters that are related to the uniformity and beneficial correlation of interactions which happen between network components.

In figure 3.1, I have illustrated the usefulness of relation (25) which has as a fundamental idea the functionality unification of the common parameters that can meet real-time communication criteria for tolerating errors and malfunctions in transmitted sessions. I have used an ordering of functions in the light of Venn diagrams, because each network and communication system that is transited, requires its own operation and standardization through protocol rules. From this I deduced that once a transmission medium is able to route data in real time, it can contain sufficient communication resources through adjacent devices that comply to the criteria of routing paths and distance vectors. These in turn can be completely different when subnets routers and switches are disturbed. Data units make use of various parameters for rerouting packets in case intermediate defects occur [WUJ16], and for the formulas I illustrate in fig. 3.1 to be clearly transposed in the real world of computer networks, I mention that time t' from relation (25) must be understood as a component of the set given by the value range Q and service rate S .

In the following paragraphs and till sub-chapter 3.1, I will present in detail the intersection formed in relation (25). The logical intersection is needed for running a communication protocol that I logically defined in order to perform the synchronization algorithm proposed fault tolerance effect.

Relation (25) contains the following performance metrics:

- λ_{ef} = the effective rate of requests entering the system;
- τ = random variable that represents the actual service time;
- $N_q(t)$ = random process corresponding to the number of range queue requests of maximum length q ;
- $N_s(t)$ = random process corresponding to the number of requests that are in service, in the s system servers;
- t = the communication time between two network hosts and/or endpoints that form the real-time communication process;
- Q' = segments adjacent to the affected one, which provide the necessary parameters that enable the take over of real-time data communications;

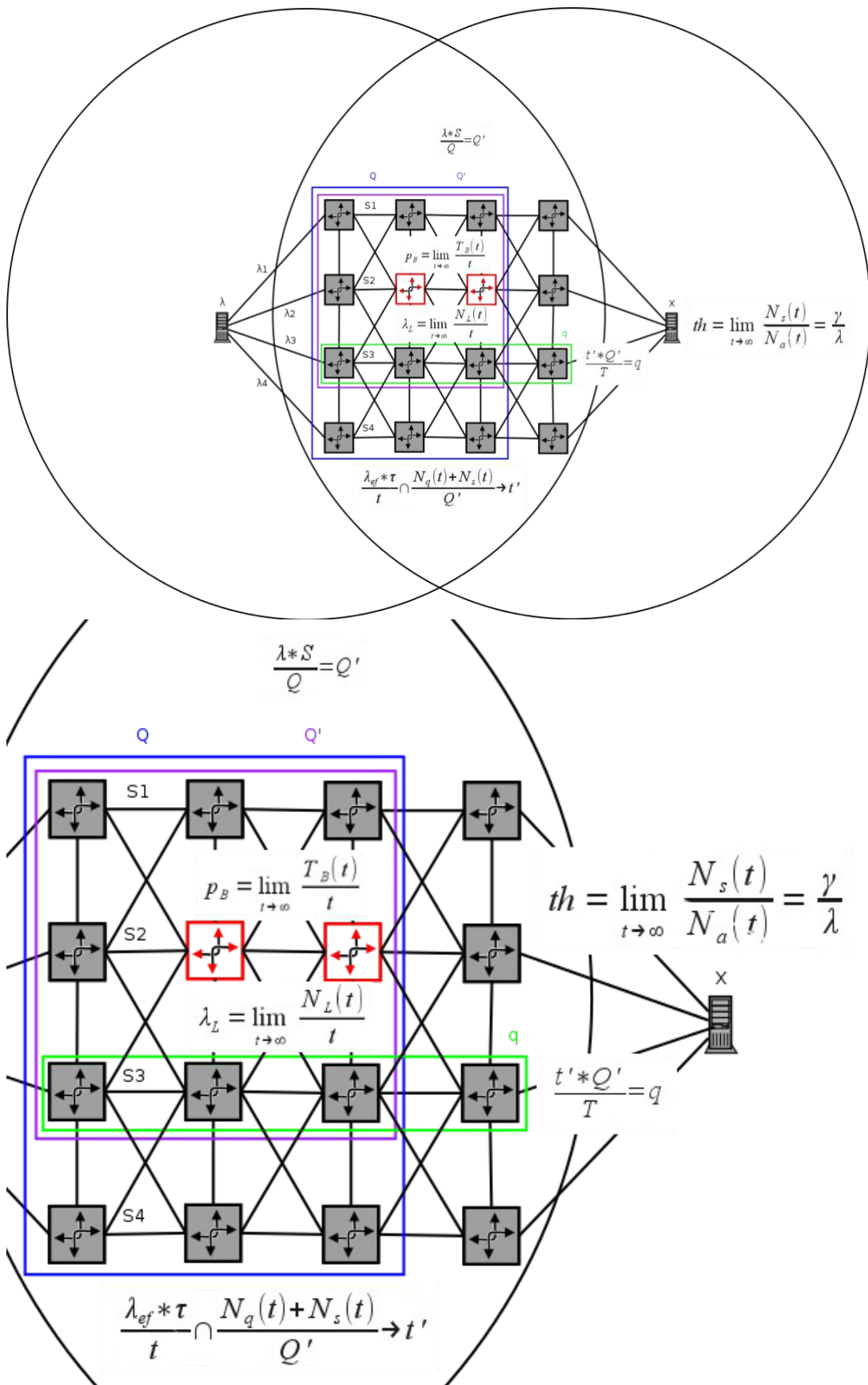


Figure 3.1 Visualization of the performance analysis in routing environments

The solution is described mathematically in relation (25) and it represents the detail of the brief presentation from the thesis introductory chapter(Chapter I). The approach is complex and it contains a multitude of network mechanisms, functions, parameters and metrics that operate interconnected computer networks only up to the network level of the OSI model. For the proposed protocol, the synchronization algorithm and the interaction mechanism to be usable in networking environments, the following mentions are deduced:

- The performance metrics that have been studied as methods to impose the self-regulation of communication parameters, need to be included in the protocol so that it can gradually analyze parameters and performance limits of routing devices;
- The self-adaptation of the communication process to the actual necessary rerouting feature must be carried out within the negotiated time limits, primarily to comply with end-to-end agreements and secondly to be applicable in terms of times τ and $N_q(\mathbf{T})$ ¹¹;
- The functions defined by the basic protocols of computer networks must be used in the decision-making process for mitigating the in-cause disturbances, these being based on the specifications of mechanisms that use performance indices which are implied in reorienting TCP datagrams;

The three points mentioned above are a highlight of computational interactions and in essence they aim to formalize for the real-time transmission process, what the communication protocol needs to do in order to mitigate possible disruptions of a transmission.

Because interaction has a well-defined role(as a concept) in categorizing actions from networks, I considered that each event(action and reaction) can be integrated with a beneficial purpose in the analysis of traffic problems and in particular in the analysis of stability and reliability.

The lead author of the OSI model specified for ISO a layered organization of functional dependencies which aims to determine the technical requirements of transmissions that are performed between various network points and with different services. These requirements mainly need a correct operation of each previous layer in order to meet the performance requirements of the level at which the analyzed service is. If layer 6 presentation requires real-time data, then all infrastructure(physical, data link and networks) and logical(session and transport levels) criteria must be met according to the presentation layer service specifications. These can be generic(ex. the bit length of an IP packet), but routing in itself is created as a process by the need to provide the solicited resources of the application/program in question.

For the session layer of the OSI model there are a multitude of mechanisms that make use of several protocols at once [KOA13]. These make general use of TCP-level variance agreements to provide for session routing processes the performances that routing devices have available. For example, the 3-way handshake also requests an acknowledgement for a transmitted data packet in order to assure the sender of the data packets, that the packet has been received. Another example is the agreement of the SIP protocol with 8 directions, in which every step of the initiation in question requires a confirmation as acknowledgement, which is used also for maintaining the established data flow. This maintenance is necessary for the dimensioning and structuring of fragmented and transmitted data packets. Examples of technologies and mechanisms that require multiple correct operations in real time are VPN¹², ipSEC¹³, RTP, and in general any connection-oriented transmission to which quality requirements apply.

Due to the fact that overlapping OSI requirements have a way of gradually edifying each technology that will be part of a transmission with specific attributes, the anomalies that may occur through disfunctions of protocol agreements are those that indicate the significance of parameters in certain contexts. There are cases where the parameters are generic, but for guaranteed quality of service these parameters are the most important. For example, the arrival and processing times of data packets

¹¹ If the times are too high per unit of equipment, the result may be the blocking of the in cause equipment or the cancellation of the data that is to be transmitted.

¹² An addition to real-time data packet time framed communications is the creation of encrypted tunnels that make an IP messages unintelligible to the entities that may intercept them.

¹³ A technology in which the mechanisms modify the datagrams of the data packets and add additional information to ensure the integrity of the data to be transmitted (AH) as well as the validation of the data origin for the interconnected points (ESP and SA).

indicate primarily the speed of execution of processing centers [PAT17], which for real-time processes are a current research topic. In order to emphasize these things, I wanted to describe as accurately as possible from a logical and mathematical point of view, the operation of sessions in real time. This description is presented in the following paragraphs by the explanation and representation of the functionality of real-time session generation processes, as well as their maintenance in an active state, with an optimal runtime.

Real-time sessions work through the transport level technology(layer 4 OSI) which takes over the descriptive indexes found at the session layer(5 OSI). This facet was designed in the form of a pre-formatting of data packets that have higher requirements than regular data packets(ex. dns, ftp, http). The packets in question are transmitted over interconnected networks in a different manner than those that do not require guaranteed communications. At a protocol level, they are separated in the environment to follow only the best routes that are able to take over, process and transmit real-time data packets. By using this method for performing transmissions, real-time is defined and operated as a preformatted measurement unit and can no longer be significantly changed in value during the operation of an endpoint - endpoint process(*end-to-end*). Real-time isn't known priorly in a transmission as being a value for any equipment, unlike telecommunications where it(the time to communicate from one point to another) must be known before each transmission initiation. In computer networks that perform routing and switching dynamically, real-time is guided by the complete communication process between the endpoints, which informs itself autonomously on the performance requirement that is to be solicited from routers and switches.

The multitude of technologies that interconnect autonomous networks and systems result in numerous subsystem processes that perform self-adjustments, adjustments of local communication times from devices and last but not least the identification of errors [SIN16]. Mentioned in the current research state of the art, was that the fundamental problem of interconnected converged technologies that are given by the ability to tolerate logical software defects, as well as hardware equipment defects. I completed this ability through this study for the case of real-time communications, by creating the concept of Interaction which I set out to identify and diagnose the collaborations between technologies. Collaborations between algorithms, protocols, mechanisms, special distributed programs, operating systems and hardware architectures that take part in running the real-time transmission processes, were analyzed in terms on how they work. In order to identify the minimum resource problems of congestion or interruption of some transmissions, I have studied the operation of each component individually and through the unit values of processes and subprocesses(sliding window autoregulation mechanism or transmission protocol reset), I deduced that all interactions which take place have logical explanations. They are presented in the following paragraphs, being explained for the context of real-time transmissions of persistently routed data.

Real-time transmission problems can occur for two reasons, namely congestion that appears due to the large volume of data that is to be routed, and physical equipment defects. We used these two causes to categorize and fragment the identified sub-problems [TAN04a] as denial of service, network flooding and lagging, and also to note minor defects such as blocked IRQ registers or channels per equipment¹⁴.

An interaction is essentially a phenomenon that appears from the actions of components interdependencies that can be negative(harmful effect on the runtime of data packets), or positive(in which logical software actions work properly, compliant with technical hardware and software specifications). To be kept in mind is that the OSI model was based on a multitude of requirements that had to be met. These were placed on levels based on their functional dependencies which need to be met by lower-level technologies. Each layer is equally important for the smooth running of network services, but the performances needed for all applications do not necessarily have to be provided. Routing is performed depending on the performance of an infrastructure device that is implemented on a case-by-

¹⁴ Although they are local per device, they can have visible blocking actions from which logical software problems and their impact on the routing environment can be deduced.

case basis in autonomous/regional systems, networks, backbone tiers, and so on. Hence the term heterogeneous network was adopted to describe the interconnection between networks that operate on the same TCP/IP principles. The devices that will route qualitatively demanding data are selected based on performances that they can meet, and the metrics defined as the processing rate in time frames are the ones that guide the transmission processes. In the context of this study, of real-time communications, the quality and integrity of data is primarily analyzed as a requirement and only if the dynamic logic of protocols¹⁵ can be performed by the hardware environment, interactions are specified as local device/network sub-tasks and are afterwards executed [PEN18].

Conclusions for the Solutions Approach

In this chapter beginning, the main ideas that compose the claimed contributions were presented. For this, the time-based parametric analysis mode was presented along with the operating logic of the protocol designed to act for real-time rerouting. Communication sessions involve a whole process of assemblies analysis(routers, switches, network operating systems, protocol algorithms) that will submit their data packets and at the same time, depending on the available technological spectrum, they have the quality indicators met.

In the following sub-chapter I will present these interdependencies as a correlation of hardware possibilities with real-time sessions protocol logic. The in-cause logic is essentially a chain of events that follows a clearly established order and must be contained in performances(top and bottom) considered to be good for persistently routing real-time data packets.

3.1 Tools and Means of Experimentation

In this thesis I addressed the issue of persistent routing through elements of data traffic simulation and timing by using the Java Modeling Tools simulation tool (JMT). This tool is useful in evaluating the performances of network actions and reactions at unit level and as a complete system.

Basically, the simulations that I have developed are abstract, and focused to reduce the complexities of evaluating persistent routing processes to performance models which express the possibility of reorienting data traffic in real time.

The performed experiments aim to concretize the simulation elements and network distributions, in performance evaluation models that represent existing contexts from the real world of information transmissions.

The used simulator offers an ability to abstract and reduce the technical problem to its essential elements, being at the same time flexible enough to represent operations of data distributions in dynamic communication environments.

As a conclusive description, the simulations that represent the performed experiments are modeled to highlight the operating parameters from networks which can apply the proposed synchronization algorithm while ensuring increased fault tolerance. I mention increased fault tolerance because today's networks have mechanisms that mitigate defects [NAK14], but the synchronization algorithm enables fault tolerance on a single end-to-end path by rerouting data on intermediate segments, considered optimal in terms of performance.

¹⁵ The parameters are adjustable for the required case.

In the following paragraphs I present a description of the graphs that are generated using the Java Modeling Tools for experiments, these being the results that were obtained and through which I validate the applicability of the interaction analysis and the synchronization algorithm.

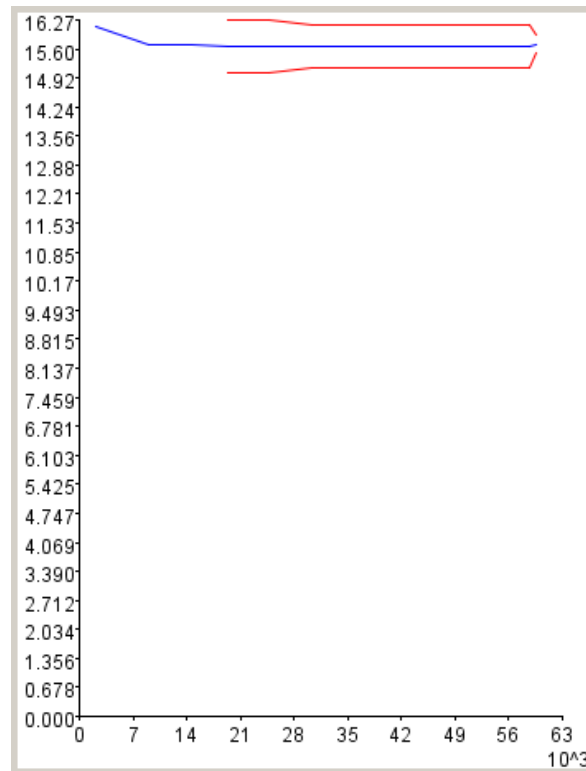


Figure 3.2 Simple graph

A simple graph like the one from fig. 3.2 is created as having two coordinates, the time set horizontally and the volume of data set on the vertical axis. The data plot is of evolutionary type, and this is to represent the dynamics of the Internet. At the base of the plotted graph, on the right side, the magnitude of the numerical values is represented by 10^3 which means 10^3 is noted. The actual data and values that are represented for a typical data distribution are illustrated by the blue line, the red lines representing the minimum and maximum limits of the evolution of data traffic during the transmission moments.

In figure 3.3 is another type of graph, a plot of ten successive experiments that can be compared visually due to the red line behavior that is drawn horizontally. The representation is the same in this case, given on two coordinates, namely time on the horizontal axis and the volume of processed data packets on the vertical axis. The type of experiment for which graphs are obtained as in fig.3.3 is called what-if, this involving parametric changes specified that are specified in the simulation model to ease the observability of performance variations in data distributions that require different data packet volumes.

As various effects needed to be represented, an important aspect of the time limits analysis was the correlation of the simulated devices and actions into meaningful understand. For this, the drop policy once an overload effect was presented, was defined as being a discard from memory of the requests that could not be completed, while the generation of random traffic(that stands for Internet dynamics) was provided via the pseudo-random generator that is implemented in the simulation tool stack.

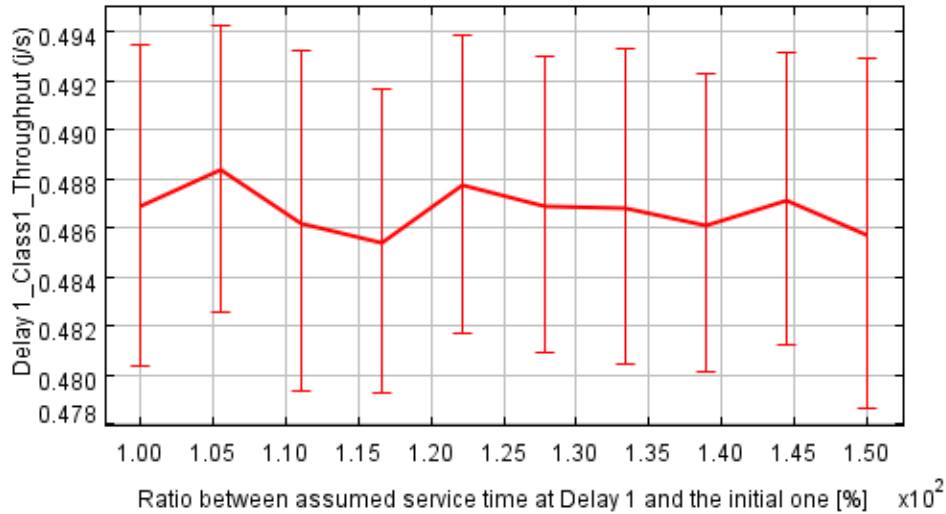


Figure 3.3 What-if simulation graph

As a final mention of this subchapter I state that the experiments that will be presented in the continuing subchapters are considered more realistic in tolerating defects through a single persistent route, when compared to two or three routes that complement each other when an anomaly occurs. If two or three routes were generated for the same purpose, at the moment a fault is identified on a route, the lost packets that would not be received would imply a deadlock for the computations of the process, significantly raising issues for the acknowledgment of data packets [HOE14].

Conclusions for the Experimentation Methodology and the Afferent Tools

This sub-chapter presented the main experimentation methodology that was used throughout this thesis, namely the simulation of discrete events with the use of JMT and its data distribution possibilities, along with what-if instances of probable cases.

3.2 Correlation of Real-Time Session Functionality

In the analysis and documentation of the current state of the art research on real-time transmission modeling, I've identified a multitude of parameters among them being the packet length, the packet header and special service indices called type of service. To achieve a tolerance of intermediate network defects in real-time, I deduced that the whole assembly formed by routing technology must follow a correct logical operation. To meet this criteria I defined a protocol that contains the ordering of each network interaction according to a specially defined template for transmitting real-time data(of sessions) through existing communication infrastructure.

The protocol proposal I make, has the role to clarify how the dependencies of sessions are related in real-time with the transport level parameters of the OSI model. This method is applicable because

from the respective information a correct¹⁶ correlation of interactions can result for interconnected networks with available resources.

In figure 3.4 I present the decision making factors that have the role to describe the process of persistent routing. These factors determine the *timing* run of the network through the mapped synchronization algorithm, mapping that I will present throughout the document with representative states from the decision support. Persistent routing involves procedural analysis because for real-time communications, the guided correctness of the transmission is given by the parameters and execution steps that are integrated in the programs of communication protocols [PAD17]. Every communication protocol requires actions that must take place to transmit data and to tolerate real-time defects, and I consider that these actions must be ordered to ensure secure and complete communications.

Discrete events characterize data routing and packet data transitions through communication paths. Generally, the states that define persistent routing are logical by nature. These involve the concrete analysis of each performed action in order to fulfill the algorithmic instructions transmission [IOA11], a mandatory requirement because each data packet contains embedded operating parameters of the transmission process.

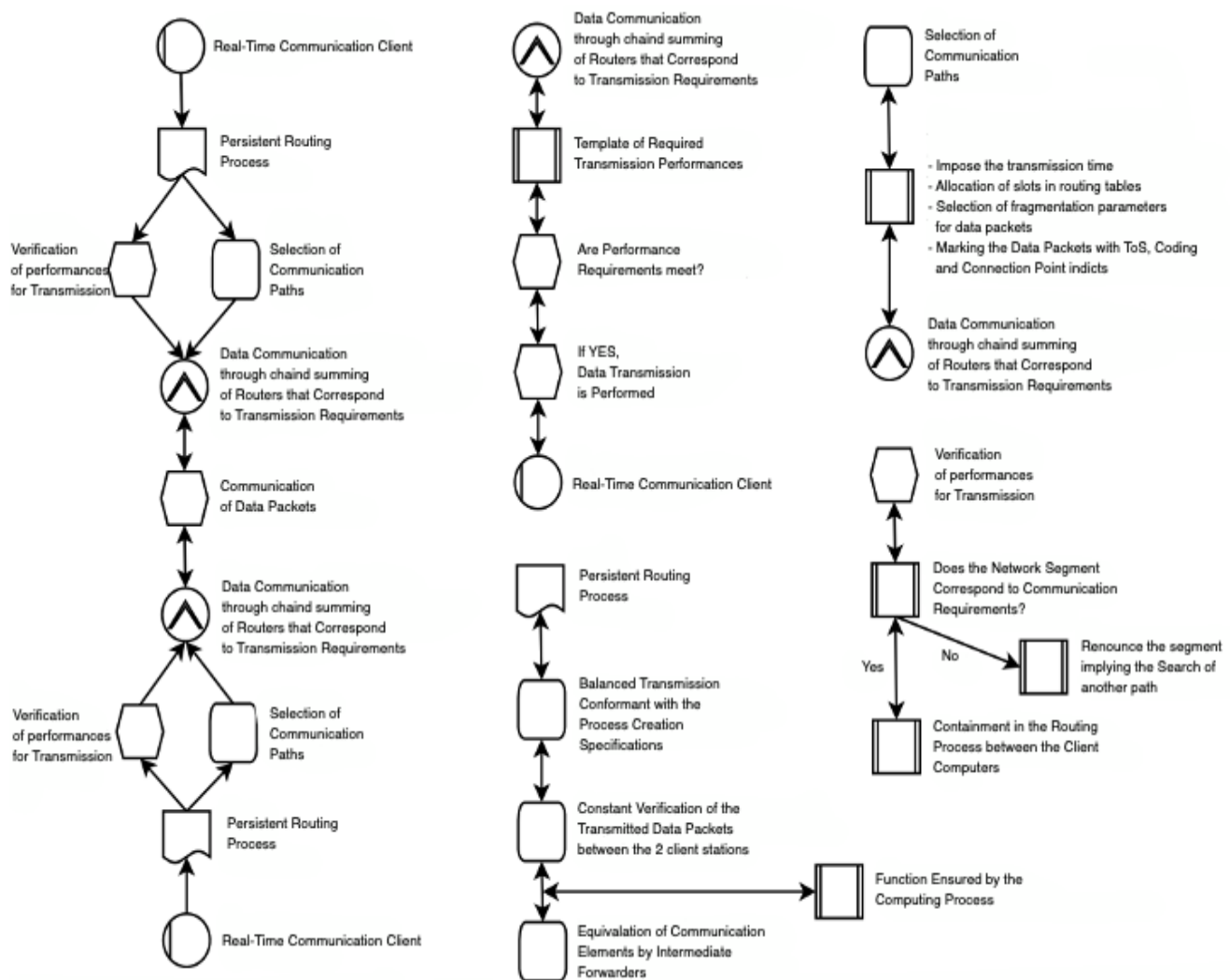


Figure 3.4 Decisions in creating persistent routes

¹⁶ Normation through communication rules.

The communication process consists of events that are described by the communication protocol as illustrated in fig.3.5, and the events in question show data packet transitions from one device to another through the persistent route that activates the real-time session. Transmissions of data are validated by two parameters, namely by the TTL fields verification of each data packet, and the transmission speed check of each segment in each stage of the communication as a whole from where the transmission rate per second results.

States defined by Markov Chains [IOA11] shape the process of persistent communication with a functional chaining of data packets that are forwarded in real time at the session level of the OSI model. Through these states, value sets can be attributed to diverse transition mapping stages of the end-to-end communication process (fig.3.6). In this way, the possibility of achieving a quantitative analysis is shown together with the routing prioritization and quality of service reliability.

A qualitative analysis is necessary in QoS because it highlights the operating limits of persistent routing(fig.3.7), while the focus of the present study is that of tolerating the disruptive effects that act on these demanding transmissions, and at the same time to ensure the reliability of the transmission(fig.3.8).

In the enumeration that follows, I describe through state representations the analysis that I have conducted from a logical point of view on the transitions that each data packet passes from one network node to another, at communication times that are set priorly. The conditions are as follows:

- a) S' = data processing to be integrated into the communication process, processing through which the degree of data fragmentation and encodings are imposed;
- b) S'' = marking of data packets with time stamps, priority flags and types of service, so they can be transmitted;
- c) S₀ = recognition of the data packet that meets the requirements of transmission;
- d) S₁ = initialization of a data packet transmission as being part of a series of packets to be transmitted;
- e) S₂ = data packet transmission from one point;
- f) S₃ = receipt of the data packet at the destination;
- g) S₄ = integrity verification of the communicated data and its timely delivery in which the packet in question was received;

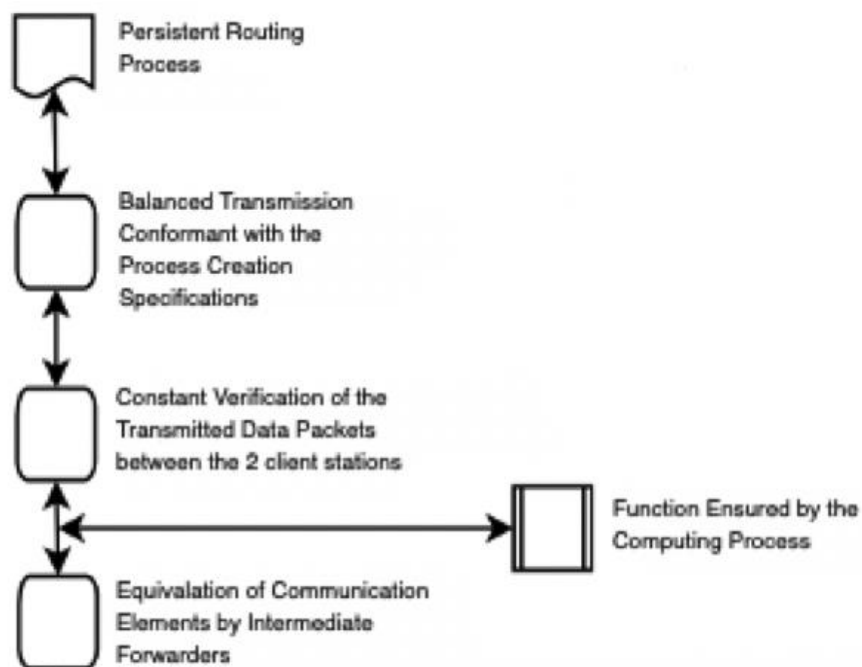


Figure 3.5 Persistent routing and performance validation process

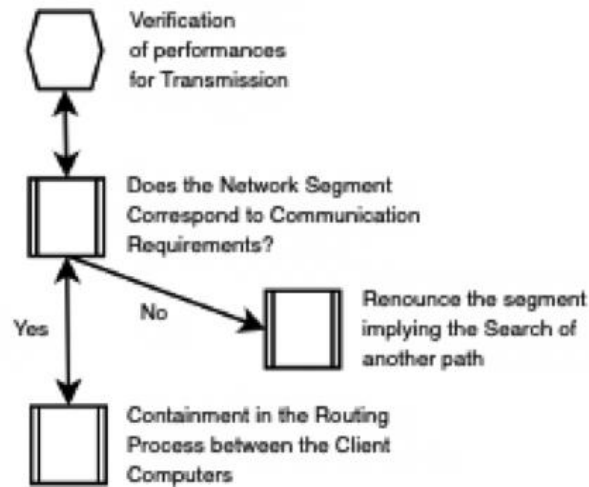


Figure 3.6 Verification of value sets for quality requirements

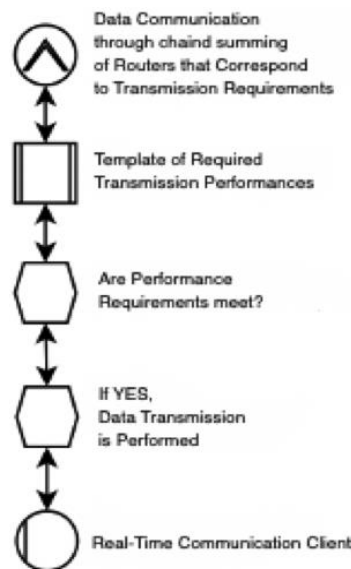


Figure 3.7 Highlight of the operating limits

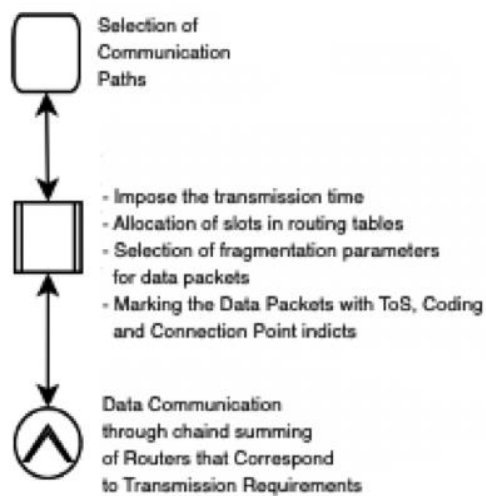


Figure 3.8 Passing of the verification thresholds for transient data packets

The enumerated states are dependent on the notions that were mentioned in Chapter II, being mainly guided by the utilization degree and throughput of networks. The packets arrival rate is also shaped by variations of task completion because a continuous acceptance of packets in state S_0 , would lead to workload conditions that cannot transmit packets in the required time limits.

In the following example I present the context in which the exact transmission of packets in represented states becomes the problem of not being able to meet the transmission requirements.

In dynamic networks it is known that routing is balanced by the search for the shortest paths not only by calculating the traffic cost, but also by implying communication policies. Network equipment function as devices capable of making autonomous decisions if the indices imposed by the policies and search metrics for the shortest paths are applied to guide the process of allocating segments for transmissions [PEN18]. At the level of a network anomaly or in the event of network unit faults, the mentioned decision support must balance the workload between network nodes. In the case of communication sessions, this action is observable because priority for quality validation parameters of data traffic are made available through the use of status agreements that in turn involve a continuous timing of packet's elapsed transmission time. The algorithmics of agreements and handshakes is in terms of timing, the constant form for checking and controlling real-time sessions. Because of this aspect, sessions can be seen as having a malfunction, since all the parameters that involve the allocation of resources in a demanding manner, are impossible to find through mechanisms that mitigate disruptive effects without having states S , S' , S_0 , S_1 and S_4 .

For a better understanding of the described example, I've illustrated in figure 3.9 a gradual visualization of the decision-making process from figure 3.4. This decision-making process is complemented by time simulations from chapter 3.3, method of analysis by which I emphasize that the persistent routing problem can be solved.

In fig. 3.9 the decision-making process is initiated by the router that's closest to the computer requesting the real-time transmission. That's because the routing pool is formed by 8 routers, and the degree of partial connectivity of the central routers from the figure. In general, any communications starts from the initiator of the transmission and is chained in every step of the route path search. For certain types of transmissions, these protocol methods are not mandatory, but for real-time session processes, the priority process also requires the continuous chaining of performances through hybrid network topologies.

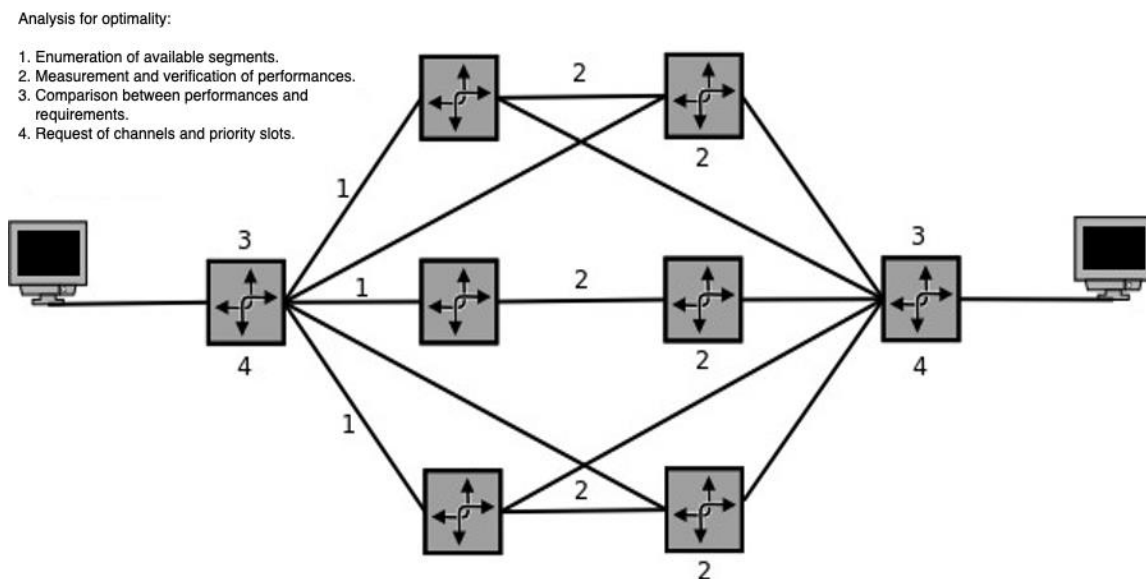


Figure 3.9 Gradual visualization of the decision-making process

The process of analyzing communication routes that's illustrated in figure 3.7 and applicable to the example from fig 3.9, is based on the following listed actions and their brief description:

- 1) Listing of adjacent communication segments to indicate the time required to complete a network hop, and also to identify routers that are active;
- 2) Querying of devices found to be active if they are able to provide the performance indices that are necessary for reorienting persistent routes(priority and uniform bandwidth and data flow), and to highlight which are the potential future alternative paths that can be considered for the reorientation of a real-time data transmission;
- 3) Selection of the communication route in accordance with the received parameters and indices, the selection being made through an evaluation of weights on the time to transmit data packets, and on the uniformity degree of the information flow that is reported by network segments;
- 4) Request of a transmission slot from the router that can provide the quality criteria with network hops that will be contained in the global transmission time till the next router. This action implies the condition that the device is not affected in any manner, while being part of the adjacent network area of the disturbed router;

The analysis of real-time persistent routes requires the application of synchronism in parametric chaining's of communication times for each equipment, correlating arrival, processing and transmission times from node to node. This correlation is necessary as the quality of communication depends on the continuous chaining of video images, telephone conversations and transmitted data [ZHA10]. Data packet chaining is performed by network mechanisms that run the necessary tasks which correlate continuous communication, and from this point on the creation of transmissions in real-time(with application transformed performances) become intelligible actions for users. The process itself also facilitates the removal of signals that can degrade the quality of real-time communications, outlining the quality of the so-called synchronous signals between network nodes.

In figure 3.9 the reorientation process of transmissions for a persistent route can be viewed and deduced as being a logical action, fault tolerance taking place only if the validation of the performance analysis is correct and the error margins are taken into account in a concise manner(neither extrapolated, nor neglected). In the synchronization process the error margins are minimized by network handshakes that have the role to adjust each packet transmission. These handshakes involve depending on the version or mechanism(can be with two actions or three, and depending on the protocol to have until 10 actions/ways), the need to monitor the integrity of the communicated data by verifying it with the checksum control of the amount of transmitted information. At the same time through handshakes a clock synchronization per equipment is requested in order to find the best time frame to transmit data packets. The request to set the interval of each clock(tick) is a subprocess of clock adjustment from devices that synchronize to execute instructions at the same time, instructions by which they will transmit certain amounts of data [DAR10].

Data that cannot be communicated within the specified intervals of computer clock ticks act a network anomaly called lagging, this being one of the causes that leads to the cancellation of real-time processes. This validation technique stands as basis for the solutions that I will present until the end of this thesis, justifying the role of simulation elements and logical modeling for integrating the concept of interaction in the OSI model. The used simulator is a software tool through which real world contexts¹⁷ can be represented, being composed of a random traffic generator¹⁸ and various parameters and indices that can be quantified in time limits.

The concept of interaction and more precisely the purpose it fulfills in the parametric and probabilistic analysis of real-time communications, is related to the functional logic of routed data

¹⁷ It is a very clear distinction between laboratory experiments, where all cases have easily predictable solutions due to the limited number of resources, and dynamic cases, where there can be no reliable assumptions about the volume of traffic to be served via the Internet.

¹⁸ That can present the dynamics of the Internet for the performance evaluation models which have been defined in the present study.

sessions [HAD14]. The concept in itself is a method for how I propose that existing deficiencies from the operation of persistent session routes in real time should be analyzed functionally and with reliability.

Degrees of reliability which can be attributed to routing technologies in real-time sessions are the technical limitations by which reliability coefficients and robustness are assigned to network transmissions¹⁹ [MUR11]. A clear distinction to be made is that the degree of overall reliability is given by the performances that were recorded without system operation errors (from a statistical point of view) and the reliability per software/hardware component that is given by the equipment unit tests.

Data packet transmissions are based on a continuous chain from one address to the next, until they reach the intended destination. The transitions related to the states that are representative for the forwarding of data packets are the way through which the concept of interaction is integrated to perform an immediate re-routing of data packets.

The existing levels of the OSI model were designed to provide a concrete analysis on the various functional connection's correctness from transmission technologies²⁰. Computer networks have become a very broad and comprehensive field of research, an effect that involves adding several types of protocols which are derived from algorithms that compute distances and mechanisms for route allocation [UED04].

Session-level transmission requests are not always managed efficiently. They have as a basis malfunctions which can be analyzed in the form of performance characteristics that are incorrectly administered, or as having a solution that's considered partially for the in-cause context [HOE14].

Being the consequence of research made to achieve certain functional considerations, the protocols that guide real-time sessions are setup and dependent on the cases in which the availability of resources is met as a requirement. I mention also that in the case of major disturbances that affect multiple network segments, the analysis metrics from these protocols are often unable to provide a method to tolerate defects. Concrete examples of these disabilities are given by the delayed action of routers that remain functional in an environment, or by the improper and unjustified increment of TTL fields. In general, delayed actions consists in finding a communication route. But, the data packets that were dropped from the memories of equipment (that would have retransmitted them and then incremented the TTL counter) are directly linked to the specification of the used protocols and the number of recorded hops²¹.

Because the actions that can't be performed are usually the object of transmissions using UDP datagrams, I chose connection-oriented communications with TCP datagrams. Through these datagrams, the protocols and mechanisms that require data security can retransmit data packets while guaranteeing their integrity. Due to the direct involvement of methods for securing and coding the transmitted information, the in-cause packets may have incremental counters that represent the number of hops in a justified way. To be kept in mind is that the global regulations of ITU, IETF, IANA and ICANN specify interconnection modes that are considered natural (security, integrity, interoperability) and because of these rules the proposal I am making is correct [IAS11]. This is mainly due to the requirements to route data packets that have unique identifiers and unique data, always taking into account existing parameters and requesting new routes in order to meet the initial performance indices.

From fig. 3.10 it can be seen that the requirements of applications that give users the ability to access real-time communications (such as VoIP transmissions) are dependent on a multitude of technologies that are intended to work together [ORZ14c]. This comes down to understanding what are the resource requirements of applications that are run by users, so that they can benefit from communication sessions which ensure the reliability of a transmission. The focus on performance requirements of the transmission media must be met by certain results, in accordance with the parameters of normal programs runtime which put into action services like video and telephony, and which have real-time data. Research in the field shows that user perception is focused on a cognitive experience

¹⁹ The degree of reliability that can be placed in the use of certain routes is based on the operation log of equipment using various technologies.

²⁰ The human reasoning and logic of system developers is generally used to integrate technologies and functions in a reasonable manner to meet the system and network design criteria mentioned in Chapter 1.

²¹ The possibility of reorienting transmissions by using counter increments has rarely been considered, because in crossed intermediate systems the possibility of interception or the validity of the retransmission requirement cannot be identified with high accuracy.

[ZHA14] which can be fulfilled by the communication media if they have a flexible operation or which can be optimized to provide even a temporary operation [SCH], that in turn is focused on session performance requirements [HOE14]. In table 3.1 I represented a cognitive analysis, and this includes elements of human interaction which can be found in the requirements addressed to communication sessions by applications users.

The cognitive analysis from table 3.1 is intended to present the correlation of transmission performances with the requirements of real-time network applications. Cognitive aspects focus on a user perceptive experience, experience rendered by the technological environment [ORZ14a]. The identification of elements that make data communications to be without lag, and not to have information loss is required for the understanding of interactions in the set of network components, this being the purpose for which I've created the proposed synchronization algorithm.

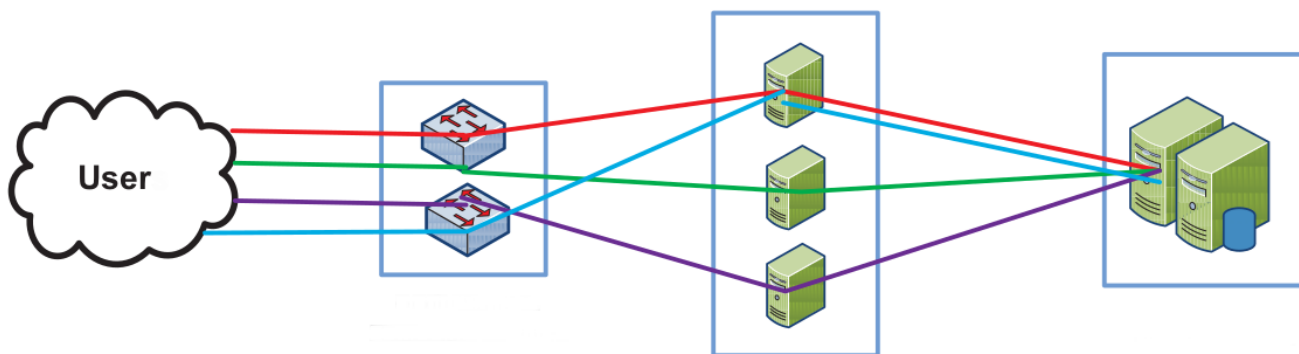


Figure 3.10 Interactive behavior [RAD11]

As an additional mention, I state that transmission media do not adapt themselves to the requirements of users, this characteristic being possible only by creating protocols that can incorporate the rules of both the synchronization algorithm and the codification and compression algorithms²².

Cognitive Analysis	
Human Interaction	Technological Component
Perception of actions	Autonomous reconfiguration algorithm
Intuition of commands	Accuracy in handling data
The behavior of the instructions	Program function processing
Attribution of importance	Application of features
Informational magnitude	Presentation of data to users

Table 3.1 Cognitive analysis of network performance [ORZ14a]

In figure 3.11 I present a model from an experiment in which I defined routing to represent the operation of the developed synchronization algorithm. It is proposed as a solution for intermediate faults in interconnected networks together with the analysis of interactions between protocols, algorithms, mechanisms²³ and variations in data flow.

²² Audio and video.

²³ Operating system mechanisms that work with indices received from protocols and algorithms to time and serve the routing requests that initiate the information flow.

The routing range is represented as having multiple data links, which are evaluated to meet the goal of evenly distributing the session data routing class in real-time. The class in question is affected during the simulations by a second data distribution that's specified with a dynamic variation(that represents the dynamics of the Internet). In graphs (a) and (b) from figure 3.12 the balance degree is illustrated as a result that can be achieved by the routing environment for the real-time session routing class, and this is highlighted through two framed information distributions that are totaled in the model(class 1 10 p / s, class 2 50 p / s).

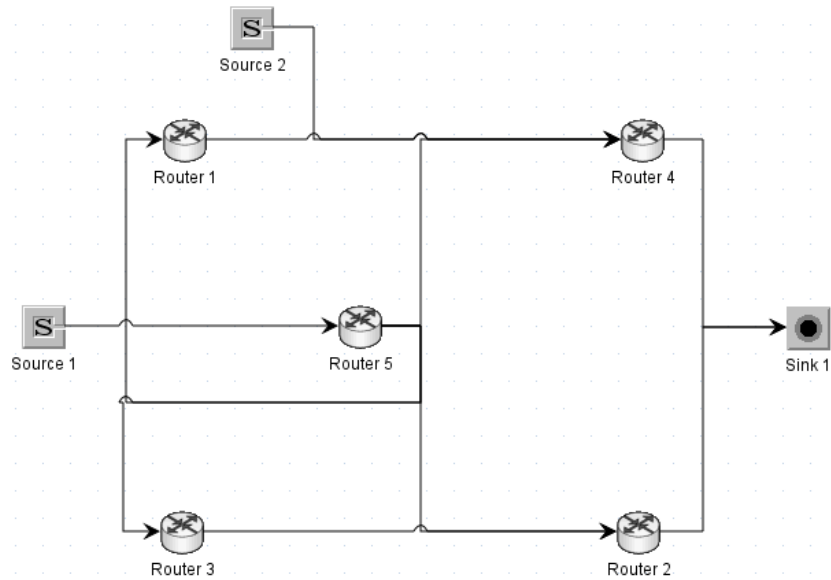


Figure 3.11 Algorithm representation model

In graph (a), the processing capacity of the environment highlights stability and an increased fluidity for the first-class of data packets, while in chart (b) the data class is the same as packet flow distribution in a context where the volume of transmitted data increases in the network. Slight variations of the data distribution performance from graph (b) indicates route allocations for optimality from routers and switches, with the aim of maintaining overall stability for real-time processes. Because of this reason, the class 1 data packets are transmitted with well-defined queues in needed time intervals, without involving time variations that imply rearrangements for all system transmissions²⁴.

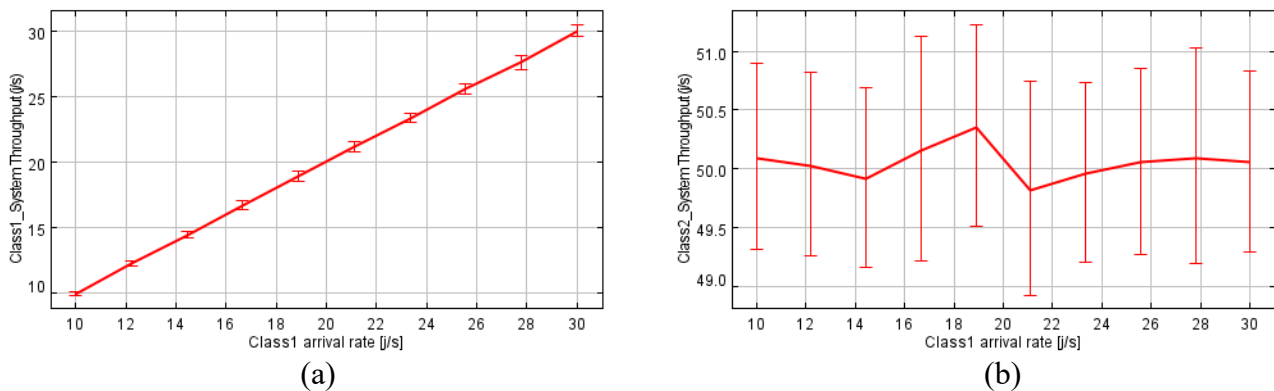


Figure 3.12 Data traffic priority

²⁴ Because the synchronization algorithm involves uniform time intervals, the growth of transmission windows in determined samples helps the endpoints, as well as the intermediate routers, to transmit in a controlled way data packets. Once established in terms of error margins, minimum limits and performance maximums, time windows can only be changed as based on condition/state reactive actions.

The evaluation of a router's performance is given by metrics and policies that are implemented in the routing equipment per class, and these are probabilistic²⁵ for class 1 and the least utilization per device²⁶ for the internet data class 2. The persistent routing data class is considered progressively in the specified model of the routing environment, and the second class shows the search for free routing regions that would not be subjected to the requirements of strict accuracy like those of real-time communications. In this manner, the simulated routing model highlights the ability to interact for a beneficial purpose, with a limited environment(that is also immediately adjacent), in order to provide good results for both real-time transmissions and additional data that's communicated through the Internet [VAR00]. I consider this a strong point of the proposed solution that I made, because the majority of solutions from other author's studies that were conducted on protocols, do not take into consideration what can be caused as a negative effect on adjacent operations of routing networks²⁷. The drop of legitimate ICMP data packets in order to keep a https transmission with video content as active, is not necessarily a positive contribution. Such types of packets(as well as other datagrams) may have an increased processing time and the total round trip delay can be summed up correctly, without the need of execution threads²⁸ that perform packet drops and data loss.

Conclusions on Functionality Correlation

Subchapter 3.1 presented how to correlate the transient states of data packets with the steps executed by the proposed protocol logic. I have created this correlation for the functionality of real-time sessions, because each mechanism that acts at this level on routing resources includes a whole set of parameters that must be adjusted to achieve the purpose of fault tolerance. Basically, the applications that make use of these network services are also demanding in terms of transmission times, all to assemble useful data for users while functioning on the basis of sophisticated performance criteria.

3.3 Performance Metrics through Data Packet Indicts and Parameters

Performance metrics must be transposed into computing environments to a level where they can be considered applicable [IYE13]. For this I deduced that guidance parameters which compose data packets are created by routing devices and protocols while being seen as an adjustable means in the whole process of reorienting a real-time process [JON11].

OSI level communication sessions use fundamental protocols such as TCP, IP, RSVP, RTP, IS-IS, OSPF and BGP, and their data is transmitted through communication infrastructures along with the performance criteria they require to be met. In the following relations I have defined the operation of protocols that ensure the interconnection between networks and the criteria for running sessions in real time.

In [BOL06] the productivity of open systems is gradually defined because the probability of a class r of data to be served and transmitted depends on the sum of the nodes that initiate the self-arrangement of the network region nodes and its adaptive times.

²⁵ It is the sum of equal values with 1 whole for class 1(persistent route data).

²⁶ It involves the length of the queue for processing, and the occupied size as processor time and memory volume by the tasks currently served.

²⁷ Certain effects lead to data packet cancellation if a rigid QoS requires it.

²⁸ Threads to delete data packets that have not left the router memory.

Definition 3.3.1: the probability $p_{ir,0}$ that a data packet class r will be transmitted by a node of an open network, is dependent of the sums of tasks j and adaptive service times s , from the adjacent connected nodes ir and segments js .

$$p_{ir,0} = 1 - \sum_{j=1}^N \sum_{s=1}^R p_{ir,js} \quad (26)$$

Routing makes extensive use of data packet transmission adaptation mechanisms and some examples of this are the sliding window and the gradual enlargement of the transition time window [ROD08]. They are used in real-time communications to continue data transmissions that at some point cannot be timed, but can be adjusted well enough to continue real-time processes between endpoints [SAL84]. Relation (26) indicates this because the metrics from protocols and routing regions require indexes as a reference and benchmark for routing [BOL06]. They are necessarily used by the parameters that assign quality in data services and automatically for persistently routed sessions.

The validation of communication parameters is generally given by performance limits. As it is shown by [IOA11] and [BOL06], performance limits can be minimum and maximum, which serve as a template for establishing the operations of the transmission processes as shown in relation (27). The blocking probability P_B helps to set the maximum quality performance (in terms of service and response times), and through them the processing rate of software and hardware queues can be measured and assigned.

Definition 3.3.2: the probability that a serial-parallel routing region P_{Bp-s} will become blocked/offline, can be found as a limit M only after a segment length productivity L_j is analyzed, given the connected nodes i and tasks j probability subtraction from a complete spectrum of outcomes 1.

$$P_{Bp-s} = \prod_{j=1}^M \left(1 - \prod_{i=1}^{L_j} (1 - p_{i,j}) \right) \quad (27)$$

The availability of resources can be considered from the perspective of two elements that define the performance of networks. These are the ability to transmit data correctly and without errors and the available bandwidth [HIR10] with a maximum limit set by the routing infrastructure. The capacity to transmit data correctly is given by the number of confirmed transmissions [KAT12], but it can only be specified if the maximum limit of the communication media is found.

The valences of the maximum limits are given by the usage of bandwidth [MAC14] because through utilization, the most basic level is specified for routing data which is to incorporate the maximum limit in the per protocol transmission capacity. The graph from figure 3.13 presents the utilizations of the CAIDA communication infrastructure that have monitors enabled for the measurement of the transmitted data volumes. This organization (CAIDA), has a research environment in which infrastructure scalability is analyzed, an analysis which as shown in the fig. 3.13, provides methods through which the bandwidth availability of networks is comprised from packet distribution counters of various routes.

To be noticed is that a related traffic capture monitor is comprised from the maximum bandwidth capacity, the type of protocol for which data is transmitted and the number of packet inputs and outputs that are going in/from the monitoring point, in relation with the bandwidth of the infrastructure. The data packet volumes (fig. 3.13) which are transmitted via communication networks are counted by the analysis metric transmitted packets per second in a whole day. The types of protocols whose packets have been communicated are also presented, these being represented in the form of transmitted amounts for a utilization degree that's reported to the infrastructure scalability.

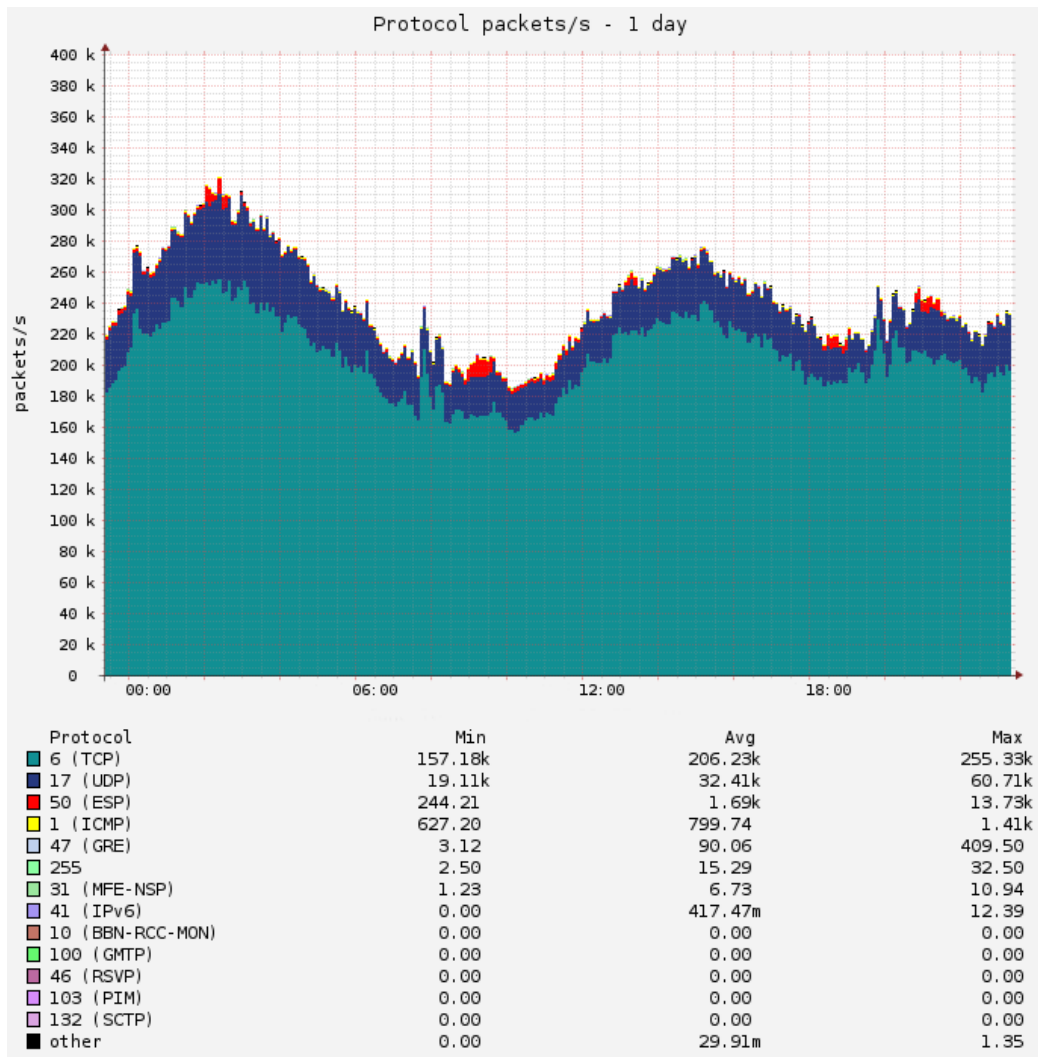


Figure 3.13 Volume of packets/second transmitted in one day, per protocol [CAI]

Data packets of several types are routed continuously or are encapsulated by miscellaneous mechanisms that are embedded in transport protocols [SIV09]. This allows in the context of persistent routing to highlight the possibility of achieving a logical transmission that's unique in the environment. The network utilization from the CAIDA analysis enables the identification of existing links between the tuning of parameters from data flows, and the sufficient bandwidth that's available to transmit data on alternate paths, in the event of a network flood or denial of service [KIS05]. Because of this possibility, I mention that instead of interrupting a real-time process, it should be possible to reorient the transmission on an adjacent segment that has sufficient resources to take over, process and route, a persistent session's packets.

The data transmitted via the Internet is considered impossible to manage, statement which is confirmed by the multitude of existing links from the dynamic topology that forms its structure [PLO13]. Also from the CAIDA analysis, it is shown that the types of recognized protocols and the volume of recorded traffic can facilitate the estimation of the underlying logical networks designs that are built over infrastructures. From these types of designs, persistent routing processes can result as having a fault tolerance means for intermediate defects and failures. Any communication infrastructure has a maximum limit for the volume of data it can transmit. Given this fact, the availability of resources for persistent

routes requires the measurement and analysis of a change history log from infrastructure flows in order to ensure the best possible level of confidence for the communication channels of the real-time sessions. In general, minimal limit thresholds of infrastructures do not exist, because the communication environment does not imply a transmission action without a prior request [RFC1122]. The limits are given by the minimum resource level that enables the correct functioning of each communication protocol, and not by the data environment that has a capacity defined of up to a maximum bandwidth.

The utilization degree shows that infrastructures have time intervals with sufficient resources and their utility can be increased for real-time transmissions. Being measurements that are obtained from routers and common forwarding points, the values mapped in the CAIDA graph may be subjected to the analytical productivity assessments from relation (28). Because of these real-world performance concretizations, in relation (29) I have formulated as dependencies \mathbf{t} and \mathbf{Q} , to be adjusted and allocated according to the service degree \mathbf{s} and number of chained tasks²⁹ \mathbf{q} , which can be correlated for dynamic time limits \mathbf{t} .

$$\text{th} = \lim_{t \rightarrow \infty} \frac{N_s(t)}{N_a(t)} = \frac{\gamma}{\lambda} \quad (28)$$

$$\frac{N_s \cdot N_a}{T} = \mathbf{t} \rightarrow \mathbf{Q} \Rightarrow \lambda_{\text{ef}} \approx N_q \cdot N_s \quad (29)$$

The effective rate for arrivals/entries in processing units/regions λ_{ef} is approximately equal to the product of the queue time N_q and service time N_s . This is because routing systems and regions have adaptive auto-control for transmissions that require QoS. Because priority transmission slots are still limited in number, session-based protocols have built-in mechanisms to partially control transmission time frames. Even congestion and data packet reconstruction through hamming codes are very efficiently calculated [KLE02], these being specified in the padding, sequence and TTL fields of data packets.

In relation (29) I formulated that the logical deduction of required protocol actions from the synchronization algorithm need to be based on the adaptive time quanta's \mathbf{t} while having direct implications on the routing space \mathbf{Q} . This is due to the fact that for the operation of the rerouting synchronization algorithm, a very concise analysis is performed on the afferent queue length times N_q and service time N_s . Starting from this premise, its worth mentioning that the effective processing rate λ_{ef} is a benchmark for communication sessions through which the first steps of the necessary criteria for running real-time rerouting are performed. The measurements for comparing the functional environment with the routing pool are initialized before the occurrence of a network problem, and the delivery times will be used in the sub-processes for measuring the necessary performances. These are directly proportional to the fault/anomaly duration, and the new synchronization time of routers for continuing session persistence must be less than \mathbf{T} global and \mathbf{t} transmission, because a routing table update cost implies such rules³⁰.

The volume of data from the CAIDA graph can be correlated with the one from figure 3.14, because packets that have a mapped variation in a finite region infrastructure are identified by IP network addresses. The in-cause addressing holds the operating limits of pretentious protocols such as those that take part in real-time transmissions, in turn involving an observable operation variation [MAT98]. Operating variations indicate³¹ how a data traffic volume is timed in a network region that has clearly established the emitter and recipient of packets. The sender and the recipient of a real-time process(both can be sender and recipient at the same time) highlight the performance of communication protocols[MCG99]. From this point of view, persistent routing has a method for applying the analysis of

²⁹ Which can reside in the router memories without exceeding the time limits set by the endpoint-endpoint real-time transmission process.

³⁰ The process of recalculating routes in routers takes time, being a quantum that has significant weights on a case-by-case basis.

³¹ Between each transmission infrastructure or for each communication process.

the proposed synchronization algorithm³², a current assessment of a communication environment that considers the recorded availability as a transaction history between entities.

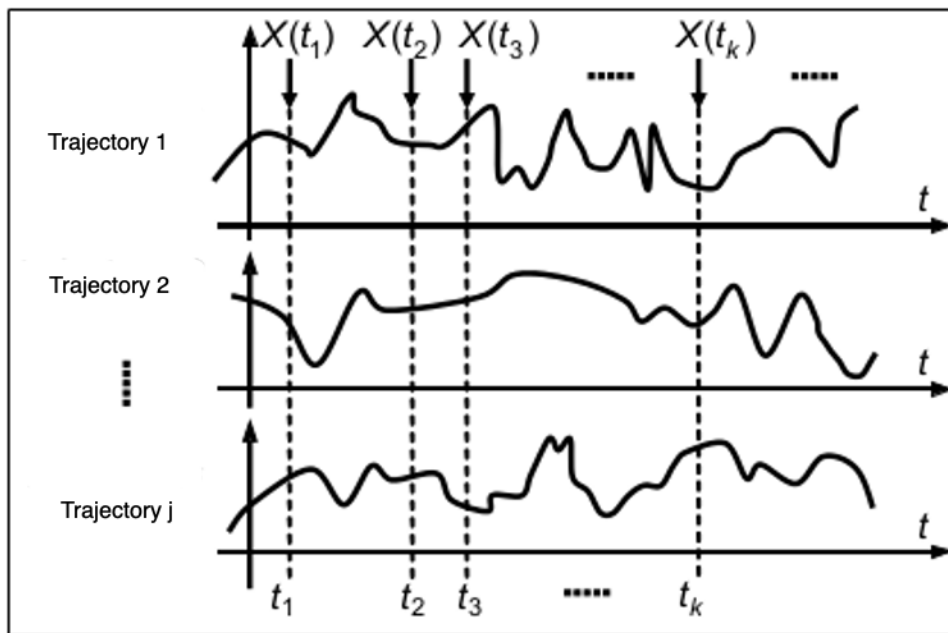


Figure 3.14 Behavior of data by environment on different trajectories [IOA11]

$$t'_p = \frac{N_q(t) \cdot N_s(t)}{T} = (\lambda_{ef})^{p/t} \quad (30)$$

Relation (30) presents that the probability to follow a certain communication path t'_p is dependent on the dynamic factors of the route selection process and time-weighted communication segments. The weight of the choices from time-based routing segments is a critical element for the proposed real-time rerouting. I sustain this statement because times must not only be minimal to communicate data from one point to another, but must also be almost constant as a communication value. From the allocation of weights to segments in the form of notations $N_q(\mathbf{T})$ and $N_s(\mathbf{T})$ results the decomposition into more fine grained measurement units, units that are specific to the local computation processes (in memory) and output stacks. All these units are concisely defined in [IOA11], because they can be contained at a higher level, where the processing of upper limits are identified, and the maximum values supported by the probabilistic computation equipment³³ can be estimated with minimal error margins.

From a statistical point of view, real-time communication performances of sessions add a significant plus to highlighting and abstracting elements that run in the communication process [LAA14]. Monitors that count each data packet from an infrastructure help in the dynamic and autonomous adjustment of route planning algorithms through the mechanisms that are used to establish the hourly comparison samples [LAL13]. They are also present in the synchronization of nodes that perform fault tolerance.

The statistics generated by CAIDA have the role to present an equalization of data transmissions with the maximum capacitive volumes that an infrastructure can support. The in-cause volume can be managed to support real-time transmissions, but in cases where denial of service attacks overload the available bandwidth, all protocols that are identified in the graph may have their transmission processes disturbed. As a phenomenon, network disturbances are the reason why the real-time transmission

³² Part of the solutions proposed by this study.

³³ Calculation and weighting of segments considered in terms of parameters and performance measurements for future allocations.

synchronization algorithm was created, a construct that has been developed using measurements and performance analyzes that were provided by the Java Modeling Tools simulation stack.

The Java Modeling Tools is a performance simulation tool stack through which I approached the problem of persistent routing, and through which I have developed the proposed synchronization algorithm. Based on Queue Theory and Markov Chains, the simulator was used in this thesis as a dedicated tool for exhibiting delays of real-time session data communications, and to highlight changes in traffic event moments, per specified time intervals. Through this tool I facilitated the performance modeling of tolerating negative effects that are imposed by the technological complexity. The simulation stack also offers the possibility to make use of a multitude of parameters that can abstract functionalities and interactions between components. By using those possibilities, I have created valid models³⁴ [ORZ14e] that contain time framed data flows which are part of the synchronization route reorientation [ORZ14f].

A multitude of simulations were performed in this study by using the JMT sub-assemblies, and the created models were based on randomly generated data traffic and utilization degrees that show the availability of resources. From the transmission capacity perspective, the simulations have had the role to identify and highlight logical components or organizations whereby the data traffic redirection solution can take place while being valid.

Another experiment that was developed is comprised from a simulation environment that's reduced to the essential components of the routing issue, these being source of data traffic, packets destination and a service center(fig.3.15).

Through this methodology, the existing complexity of transmissions composed from various protocols and devices is reduced, making easier the identification of problems and their causes. This is stated with relation (31), that involves the identification of causes through which problems may arise. The magnitude with which negative effects perturb routing environments can be estimated as shown in relation (32), and from it I consider that logically coordinated interactions can apply fault tolerance.

$$E[N_q] = \sum_{j=1}^{\infty} (j-1) \cdot p_j = \frac{p^2}{1-p} = \frac{\lambda^2}{\mu(\mu-\lambda)} \quad (31)$$

$$g = E[N_s] = \lambda \cdot E[\tau] = \frac{\lambda}{\mu} = p \quad (32)$$

In the simplified model from fig. 3.15 the necessary(basic) signaling elements of data that is to be communicated between source and destination are completed by the required queue time for recording packets in the processing catalog [ORZ18]. In general, the queue time $N_q(t)$ provides the limits that protocols use in establishing agreements with networking devices.

The model from fig. 3.15 aims at presenting performance measurements in terms of persistent routes operation and through the undertaken simulation, the queue wait time $N_q(t)$ (of packets to be transmitted) is highlighted. In this way, we focused the dynamic routing strategy on the properties of continuous transmission effects, in order to make possible the analysis of stable data packet flows.

The source and destination from the experiments indicate the points for which the service center(the queue server/station) must coordinate the process of transmission pacing(timing) without any variations in work tasks completion that would show different time frame durations(variance).

³⁴ Each context and case described by the models that are to be presented highlights situations that can be applied in the real world.

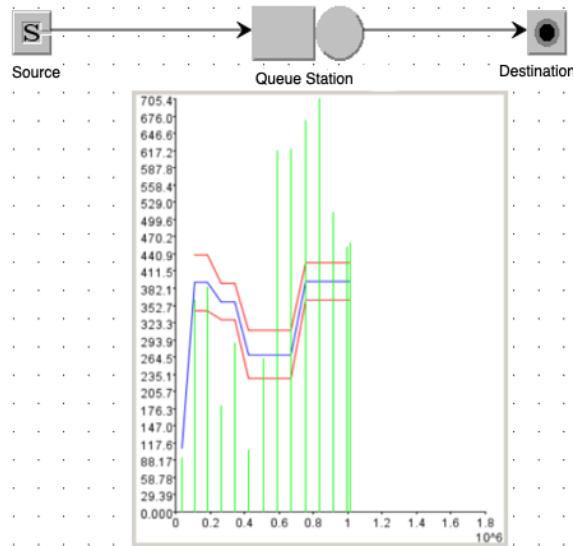


Figure 3.15 Simplified model [ORZ14e]

Fig. 3.16 continues the series of performed experiments with an extended simulation model that includes a source and destination, two servers (transmission and reception assembly) and three finite capacity routing regions.

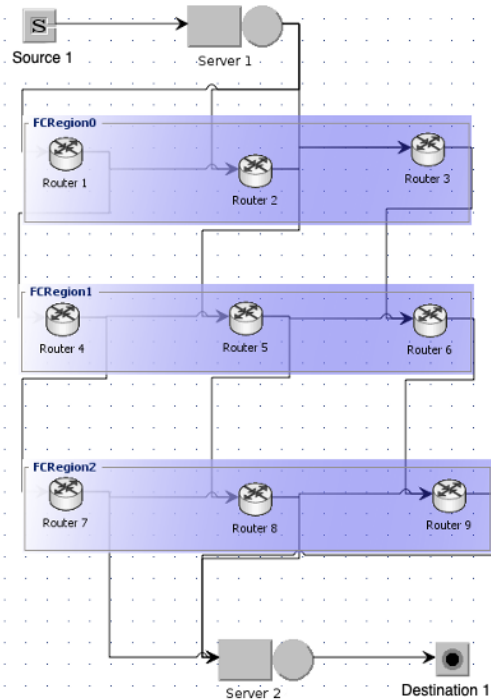


Figure 3.16 Extended Continuous Transmission Evaluation Model [ORZ14e]

The model is completed through the definition of distributions that determine the service properties of data traffic, these being distinguished by two classes that have different criteria for evaluating their related transmissions. In essence, the model expresses the possibility to simulate the phenomenon in question, namely the transmission persistence between two points in real time. Its mathematical formulation is described in relation (33), where productivity γ is given by the probabilistic

transmission mode of the effective packet rate λ_{ef} that enters the system. The first class requires more priority for transmitting the data packets that are related to sessions, while the second class is added in the experiment to act negatively on the performances of the communication environment.

$$\gamma = \lambda_{ef} = \sum_{j=1}^{\infty} \mu_j \cdot p_j = \mu(1 - p_0) = \lambda. \quad (33)$$

The two points which I want to highlight in the model are represented by the source and destination of packets, elements for which the transmission process is formed. Routing regions are waypoints that must be traversed by packets to reach their destination, and the entire reorientation process is dependent on them in the case when a fault event occurs.

Between the source and destination is the transmission of two classes, one being the class of persistent routing that requires a balanced transmission, while the second class is dedicated for the dynamic data traffic(generated randomly) representation. The second class was applied to act on the capacity of the modeled network, forcing the communication environment to adapt autonomously and to show the stability of the communication process related to the first class.

The operation of network devices is defined by the organizational logic that's applied in communication networks(prefixes, subnets and routing tables). The goal of the experiment presented in fig.3.16, was to emphasize the availability of resources that is needed for persistent routes. The organization was also represented in the environment by the dynamics of route selection through effective routing policies terms.

Finite capacity regions have the role of showing the utility of performance limits in routing environments [LUP04], shaping the flow of data in order to achieve balanced communications [GIA13]. Altogether they show at the same time through the described model also the data traffic routing, a functionality mapping that's composed from well-defined sets.

The availability of resources is a system feature that I have modeled with the use of queue theory. Because of this fact, the communication problem is identifiable in the experiments I undertook through the distribution of data and the multitude of data packets that can be found in communication networks. In the created models I imposed³⁵ the routed data classes to be different, of priority order for persistent routes, and the prioritization process having the role to streamline transmissions.

In the graphs from fig. 3.17 the utilization of routing environments is presented through the prism of the model servers. Monitoring these two units provides indicatives regarding the flow correctness for data packets that pass through the communication environment, points by which I made the synchronization algorithm analysis possible. At the same time, through the use of those two components, I specified for the criteria based evaluation model that transmissions negotiations need to have a total communication time t as a starting point for identifying nodes that can support a fault-tolerant communication t' .

The illustrated model is identifiable in very large environments, which depend on topological descriptions of graphs by which international standardization is applied worldwide [VER11]. This is because the persistent routing process functioning in an extended environment is complete in terms of the components that its comprised³⁶ from.

³⁵ With the aim of maintaining real-time transmissions as active.

³⁶ These can be logical or software, and assemblies with sub-assemblies through which a performance parameter or characteristic can be analyzed.

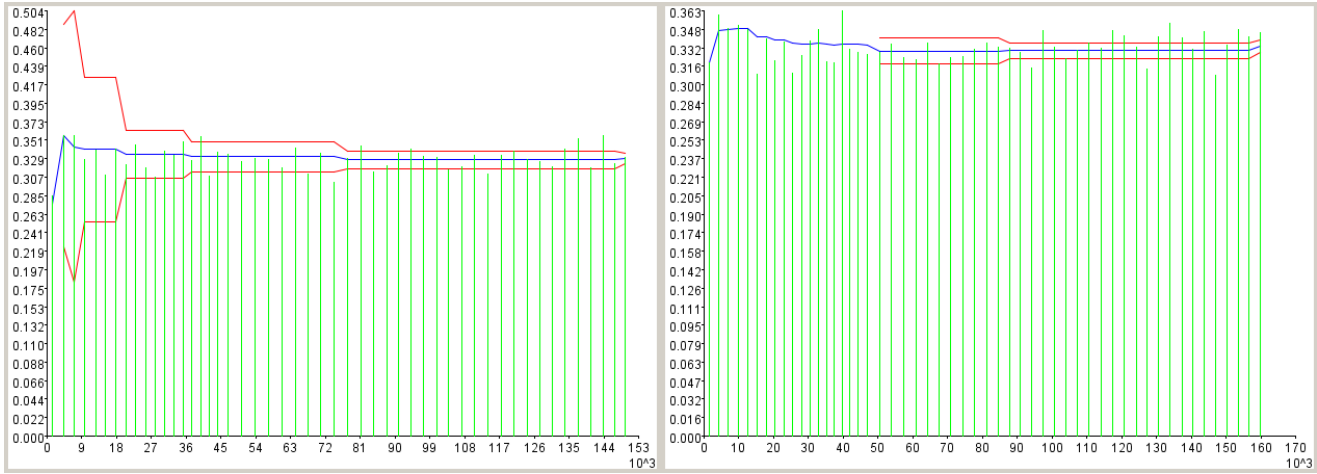


Figure 3.17 Resource utilization of servers 1 and 2 of the extended model [ORZ14e]

Also from graphs of fig. 3.17 it can be observed that stability is achieved in the performed simulations for the real-time routing class, the model being mainly focused on determining the availability of resources. The used resource measurement metrics was applied in order to evaluate the communication process, while defining the component through which time t' can also be identified in terms of the volume of transmitted data.

$$g = E[N_s] = \lambda \cdot E[\tau] = \frac{\lambda}{\mu} = \frac{\rho}{1} \quad (34)$$

In relation (34) g is represented as the utilization degree for resources. Although some performance features may be available and do not pose a problem, queues and slots from routers are finite, resulting in a limit and a performance indicator that can be analyzed [WAN13].

The choice of an alternative means for a session to continue an affected transmission on certain network segments is the main factor of the proposed solution. Both statistically and scalarly it has been shown that in most cases there are adjacent communication routes as being available and with sufficient resources(in intermediate networks) [HOC10], and these can be selected to continue the transmission of data from persistent routing protocols. To be taken into consideration is that the alternate route that will be chosen(conformant with the t' allocation criteria) is to promote the continuous and immediate operation of the transmission process.

$$t' = \frac{\lambda_r}{N(t)_r} \rightarrow \frac{N_q(t)}{Q_r} \quad (35)$$

From formula (35) it turns out that the choice of a path is facilitated by the assigned reliability indict of each transmission path, the indict r being specified in the protocol analysis because it is necessary for the identification of links and routes that are considered reliable. This indict is granted during the process runtime the operation on parameters, and it shows that a selection had taken place based on a performance measurement that's in line with expectations [BYH14].

Every router has at its disposal additional segments to allocate routes, but in the process of allocating a total route, which will comprise t' , the selection is carried out following an autonomous decision made by the network which is guided by the communication protocol indicts. In this way, the whole process for selecting an alternative route will include the number of adjacent connected segments(located in the immediate vicinity of the affected router), and the first neighbors of this router.

The need to define the selection pool is given by the fact that topologies, functions protocols, and routing tables update mechanisms are implemented to make the choice of the shortest paths in extended networks, a mode of operation which makes internet traffic run [FAT14]. When renewing routing tables, devices provide a new index with all the segments that are left as active [ORZ16a]. This index contains the route counts which can be selected in order to direct traffic to other equipment, routing phenomenon that may include types of services and continuous flows.

Not to be ambiguous, I mention that the results presented in this chapter are a representation of the synchronization algorithm while being applied on the simulated routing contexts. In these contexts, the obtained performances indicate a degree of confidence/reliability that can be given to the algorithm.

Mentioned at the beginning of chapter 2, the measurement metrics for network delays are at the center of the synchronization algorithm and interaction concept development. Through them I have built the operating relations between the transport layer and the session layer(of the OSI model), and I have created the algorithm and its utility demonstrations for accomplishing fault tolerance. Logically, the created algorithm consists from the defining components of any persistent routing process, namely the network search space and the criteria for allocating a route for a transmission, mention also made by the authors of [CIA11].

In the following sub-points, the components necessary for the operation of the rerouting process are presented along with their notations. These are the available routes and the selection pool, and they are described for the needed logic of allocating an alternative route from a multitude of routes as being available.

- a) Q = available route;
- b) $(Q_1 \dots Q_n)$ = the selection space composed from the available routes that can offer the choice of an alternate route with the corresponding requirements;
- c) $(Q'_1 \dots Q'_n)$ = limited space to allocate a resource after performing the appropriate requirements analysis;
- d) Q' = restricted space for the allocation of a communication route;
- e) q = chosen route;
- f) $f(q) = Q \rightarrow Q' \Rightarrow q$ = route chosen for routing reorientation;

Because the process of analyzing an alternative route that can be selected depends on the availability of resources, the definition of routing criteria is mandatory to be set in the protocol agreement rules [ZYA14]. Starting from this premise, a search space that includes adjacent devices(neighboring) to the disrupted routers in terms of routing actions³⁷ must be considered. In defining the search space for the links to be chosen, are the fundamentals of dynamic communications from networks [VAW14], possibility that exists because of the logical structuring of routers.

Necessary to be understood, is that from the dimensions that were defined for identifying ways that will be the solution of reorienting a transmission, is that they have dependencies between them and the dependencies are in turn formulated to allow the choice of route q . Through relations (8) and (9), I have defined the choice of route q from the value pool $Q'_1 \dots Q'_n$, pool that results from the evaluation of the selection space $Q_1 \dots Q_n$. These relations impose the conditions of general performance requirements that need to be met by the new communication route once the functional process provides numerical runtime cues, which are then used as a comparison template [LAZ84].

$$N = \frac{X}{R} \quad (8)$$

In (8) X is defined as the throughput notation, N represents the number of tasks/requests, and R is the response time. In (9) U is considered to be the notation that represents the utilization degree of

³⁷ Enumerations and weight assignment based on parametric values for adjacent routes.

resources, X is the transition degree(volume of data successfully processed), and S represents the service time of the processing station [LAZ84].

$$U=X \bullet S \quad (9)$$

The conditions mentioned by the throughput degree X together with the use of transmission points U , allow the deduction of the selection space Q' . Given that the transmission time of components must be satisfied as an operating requirement, q is defined by relating to the performance characteristics of relation (36).

$$q=\frac{X \bullet S}{T} \quad (36)$$

S represents the service time of the workload which multiplied by the degree of passage X , provides a product divisible with time to complete work tasks T , resulting in the identification network of the node that can continue a session's transmission. It is primarily framed in the precedent transmission parameter that holds a service time as a node content within the transmission limit, and is an optimal choice to submit given the time intervals T . The granular actions from the interaction analysis are implicitly complemented by formulas (31 - 35) in order to fulfill the fine(granular) adjustment of the communication parameters from protocols through which real-time sessions are routed.

To be remembered is that the choice of a segment that will continue the communication between two points comes down to a router that can take over unconfirmed data packets from the affected segment, and to transmit them to a neighboring router that is not disturbed, point from which routing continues till the destination is reached [ORZ14f].

The reorientation process of a route contains handshakes with neighboring routers that before the agreement was established for continuing a session, it confirms whether the devices can meet the requirements of real-time data transmissions. From this point it results that from the chosen equipment to transmit data with priority, routing is performed persistently on a newly selected route with its afferent devices.

The following model(fig.3.18) continues the series of analytical experiments which I've developed and with it I present the possibility to transmit data on an alternate route between two hosts/network nodes. The created model consists from the application of rerouting rules if the transmission cannot be continued by a node that is overloaded with tasks. The transmission process is focused on including the optimal communication times between the data packet sender and receiver, points from where the selection of a new route can be deduced and performed.

The model is composed from two traffic classes, source and destination of data packets, two delay stations which are the equivalent of Internet transmission delays, and three routers that exemplify the data packet routing. Data traffic class 1(the one that exemplifies persistent routing) was applied as distributed and with priority in routing. Data class 2 packets had the role of acting on the routing system with a volume of tasks that was gradually increased to be 100 times higher than that of the first class. Given that the chosen routing policy criteria was mainly the allocation of priority weights for class 1, response times were considered essential for measuring the model performance.

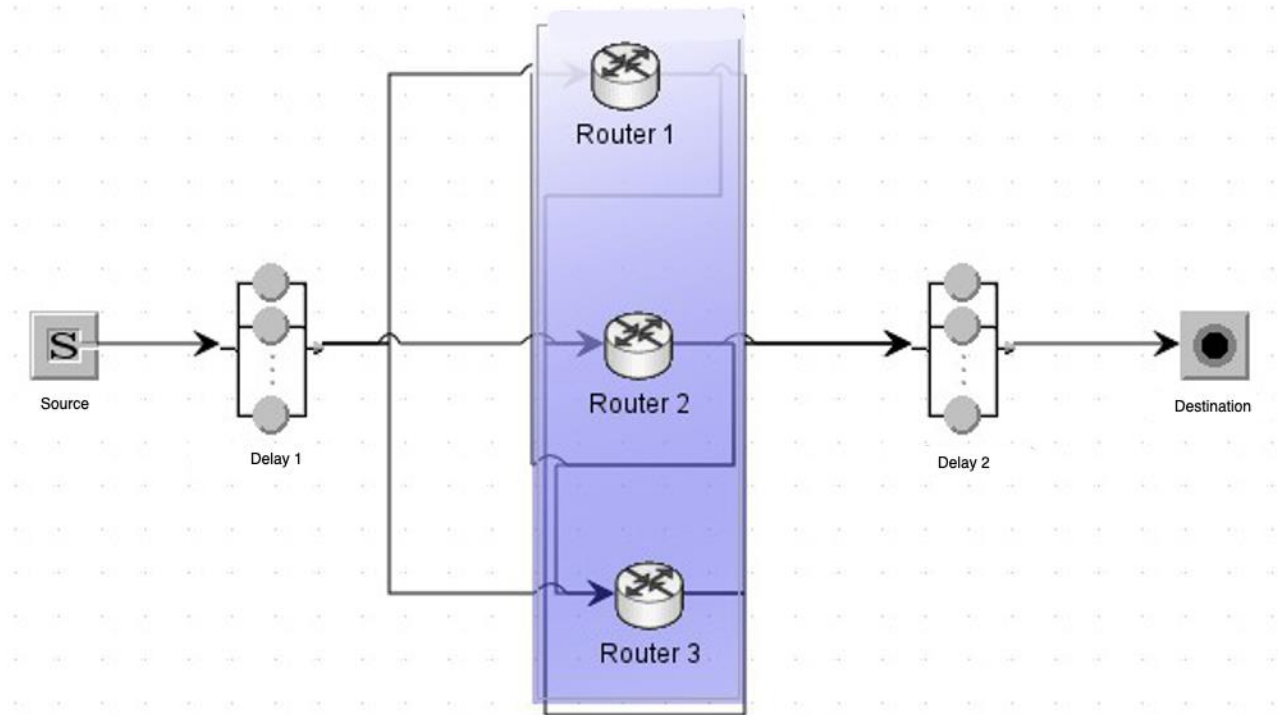


Figure 3.18 Routing phenomenon evaluation model [ORZ14d]

This experimental context was created to facilitate the causal analysis which leads to a decrease in network performance, and I defined it through the complete measurement of workloads between the source and destination. Gradually, the simulated equipment was subjected to the actions of a volume of loads that increased in 10 specified time intervals, all of which being required to best describe the accuracy of the transmission algorithms that have an established environment at their disposal. Through the graph from fig. 3.19 and table 3.2, the performance degree of impairment in terms of response times on requests j (ro. load requests) is represented. From there, the possibility to maintain the stability of the class 1 data traffic results as a process which can work only if additional segments can take over the volume of generated traffic.

The main metrics used to highlight the method of reorienting persistent routing were selected as possibilities to manage the response times of routing equipment. These metrics also offer the rendering of network nodes mapping topologies according to data traffic volumes that reside in the communication environment [ORZ14f].

The performance indices that are present in the conducted technical evaluations were based on the abilities offered by the technical specifications of algorithms that are embedded in the routing protocols from the transport and session layers of the OSI model.

From the graph of fig. 3.19, the possibility of a route q allocation can be deduced, while having as metrics for formulating the task completion degree, the response times of class 1 and the arrival rate of data packets as workloads that are recorded in the system by time frames.

The simulation included a workload percentage increase which was intended for transmission, all transitions being calculated with reliability values that are assigned through terms of very low error margins.

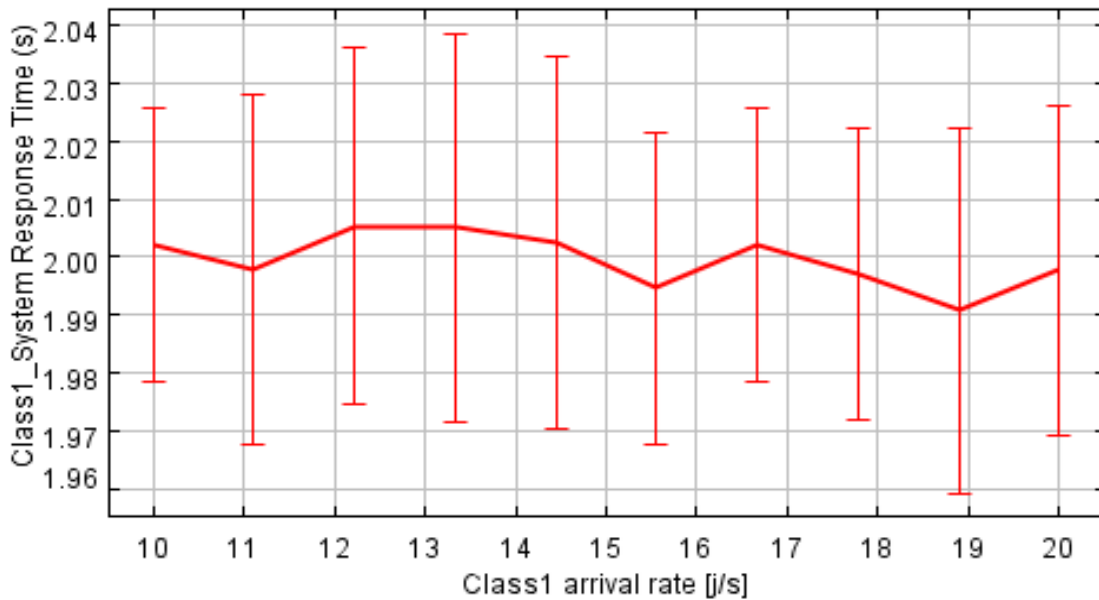


Figure 3.19 System response time

Workload	Reliability Confidence in Performance		
	Value (s) Max(s)	max(s) (confidence)	min(s) (confidence)
10,000 j / s	2002	2026	1,979
11,111 j / s	1998	2028	1,968
12,222 j / s	2005	2036	1975
13,313 j / s	2005	2039	1972
14,444 j / s	2003	2035	1970
15,556 j / s	1995	2022	1,968
16,667 j / s	2002	2026	1,979
17,778 j / s	1997	2022	1972
18,889 j / s	1,991	2022	1959
20,000 j / s	1998	2026	1969

Table 3.2 Degree of performance impairment for response times [ORZ14d]

In table 3.2, the **Workload** column represents the total number of loads per second generated as traffic in the model. Column **Value(i) Max(s)** represent the degree of maximum link usage of the model in terms of the number of packets that ran in a simulation's time interval. Column **Max(s) (confidence)** exemplifies the estimation of the maximum guaranteed values that are to be transmitted, and the column **min(s) (confidence)** shows the minimum volume of data that can be guaranteed in the simulated transmissions. It should be noted that the slight numerical variations between the 3 columns next to the

total volume of transmitted data are due to the operation of algorithms for finding routes and establishing the global optimum that can be different in each amount of sampled time from the simulation.

Conclusions for Performance Metrics

In this subchapter the multitude of metrics used to demonstrate the applicability of interactive analysis were presented, and last but not least their chained ability to interpret, identify and manage network phenomena that occur in real-time transmissions. The usefulness of metrics and quality indices is given by the routing environment and the available resources, possibilities through which I gradually defined the logical analysis mode for optimal rerouting decisions of OSI sessions.

3.4 Application of the Synchronization Algorithm

The elements presented in the previous subchapters have had the role of identifying the possibilities of routing through the transmission environment scalar abilities and to show what benefits can be achieved with the application of the interactional analysis.

The fault tolerance feature applied by the synchronization algorithm requires that the decisions taken at protocol level to be attached to state representations [WUJ16], all being necessary to order the logic of interactional functioning in communication sessions.

The cause of the transmission program that is addressed in this study is given by the interruption of a real-time communication process, interruption represented in fig.3.20 as being caused by the network equipment marked with red color and the segment through which data can no longer traverse. Such a case can happen as an operational consequence from which it can be shown that certain resource limits cannot be met. These limits are expressed probabilistically in relations (37) and (38), and have their notations significance explained in the following paragraphs [IOA11].

$$p_0 = \left(\sum_{j=0}^s \frac{a^j}{j!} \right) \quad (37)$$

From expression (37) a first shortage of resources can be identified by using the stationary probability p_0 , an effect that results from the inconsistency of a hardware-software functionality. More exactly, the performance processing from routers a^j are operated algorithmically and procedurally in an incorrect³⁸ manner for large workloads $j!$.

$$p_b = B(a, s) = \Pr[N(t) = s] = p_s = \frac{\frac{a^s}{s!}}{\sum_{j=0}^s \frac{a^j}{j!}} \quad (38)$$

The blocking probability p_b from relation (38) shows that a maximum load threshold can be reached in terms of workload processing. From the mathematical expression (38) it can be deduced that the working memories(RAM), the processing units(CPU) and the intermediate mechanisms(IRQ

³⁸ To be kept in mind is that software blocking is directly related to a volume of traffic that cannot be known priorly, but only estimated.

channels, buffers and caches) are at a maximum operating level $\mathbf{B(a,s)}$, and cannot register new tasks $\mathbf{N(t)}$ that require processing \mathbf{s} . This phenomenon is usually specific to dynamic cases in which systems are partially affected by physical defects, DoS attacks and disruptions of various software chained mechanisms(ex. internal clock, irq channels found in operational discordance with memory units).

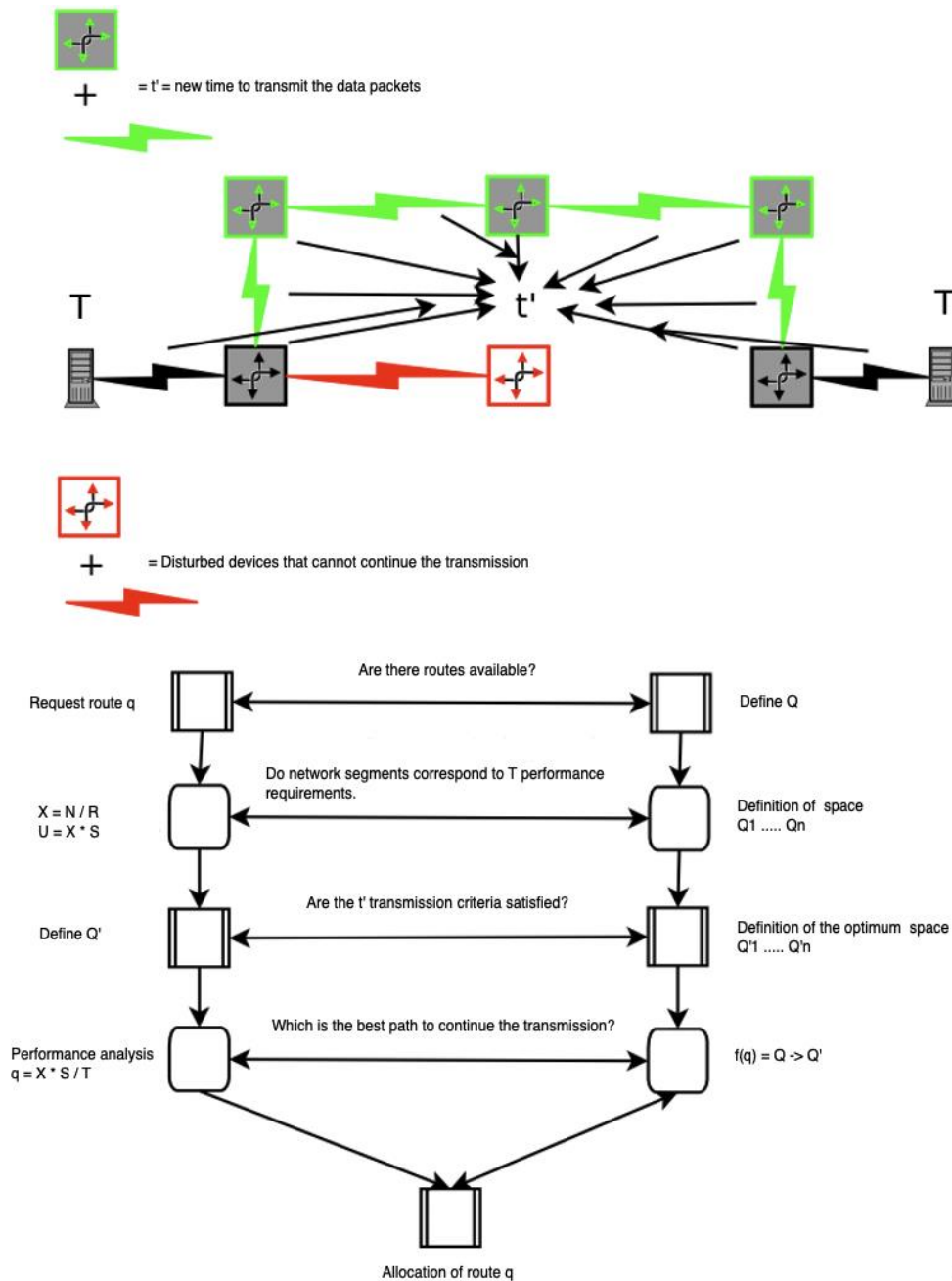


Figure 3.20 Decisions of the communication rules for the synchronization algorithm

A descriptive logic is required to integrate the synchronization algorithm among the coordination rules of real-time transmission protocols which are based on the calculation of the time quantified metrics λ , $\mathbf{N_q(T)}$, $\mathbf{N_s(T)}$, \mathbf{s} , $\mathbf{\tau}$, $\mathbf{N_L(T)}$, $\mathbf{N_d(T)}$ and $\mathbf{p_b}$. In fig. 3.20 I represented the possibility to integrate the synchronization algorithm in order to tolerate faults from environments that transmit data packets which are related to real-time sessions. Also, I have illustrated the persistent route by which data is transmitted between two hosts that communicate in real-time, process that uses time-framed transmissions efficiently.

$$\lambda_L = \lambda \cdot B(a, s) \quad (39)$$

The loss rate for tasks λ_L that is expressed in relation (39) is another system reaction that can occur if the maximum performance limits are exceeded [IOA11]. Generally, this metric provides immediate deductibility of attack types such as denial of service, or scalability issues of either hardware³⁹ or software⁴⁰ nature [SOM00].

While the persistent routing problem is given by an affected route, choosing a new path and rerouting is a process that can only take place if the selection of the new route is the best (in terms of performance) for the real-time transmission. The route that is to be chosen to continue the communication of the OSI session must be selected in both terms of resource availability and availability of alternate paths.

Communication rules are logical requirements and criteria for operation that are essential for the description of the persistent routing protocol. As it is known, these rules are applied as chained rules to be met for the routing process. As a contribution, the protocol is defined by the OSI model assembly, and through the synchronization algorithm, a hierarchical correct link results as a correlation between the transport level and the session level. The correctness in applying protocol rules is at the current research level of the domain at a standstill when regarding the attributes of quality and stability from interconnected computer networks. Being protocols that have a specific way to ensure the operation of real-time sessions, they are complemented by the created algorithm to ensure the characteristic of reliable technology.

The synchronization algorithm can be analyzed in communication networks from a functional point of view because the communication criteria from persistent routes can be modeled with probabilities, transmission path weights and Markov Chains [IOA11]. In this manner, the communication processes that are performed by the components which act variably and randomly, are identified by the devices that route data packets as continuous or discrete processes. These processes are found in the routing tables of communication equipment, having the role to logically partition the service types [GIA13], an organization method through which synchronization is allowed to run in order to assign the effect of workload fault tolerance.

From a functional point of view, I represented the protocol actions from the proposed algorithm in relation (40), in the form of a logic by which the routing environment \mathbf{Q}' is analyzed to meet the optimal route selection \mathbf{q} .

$$f(\mathbf{q}) = \frac{t' \cdot \mathbf{Q}'}{T} \quad (40)$$

Guided in the form of protocol operation rules, the synchronization algorithm that's illustrated in analytical form (fig. 3.20) is better than existing solutions. This is because unlike other protocols that retain unused resources (ex. RSVP), the created protocol is focused on finding immediately required resources. The logic behind the criteria-based selection, is that the neighboring adjacent rerouting is much more efficient than the reset of packet transmissions and fragmentation of packets at egress or ingress levels. This efficiency is because in performance environments, there is the possibility of incrementing data packets lifetime (TTL) that reside in router memories when a retransmission is requested. Another case would be a high traffic cost for retransmission from the egress/ingress routing points, a transmission time that would be too long to keep the real-time process active.

In the following paragraphs I present the synchronization algorithm mapping. It is described mathematically by using Markovian state metrics through which the route \mathbf{q} can be made available by

³⁹ Equipment performance.

⁴⁰ In which the algorithmic processing cost is deficient in the processing of data packets for certain types of protocols that forward information to its destination.

the routing environment. In relation (32), I have logically defined $f(\mathbf{q})$ with route \mathbf{q} as a result, but this function is fragmented into several fine grained quantifiable units which I present in the following enumeration.

- a) $\lambda = \lambda_1, \lambda_2, \lambda_3, \lambda_4$, where λ represents the data packet arrival rate and the four routes from fig. 3.21 are presented as having different arrival rates for the first four devices that are connected to the service center;
- b) $S = S_1, S_2, S_3, S_4$, where S represents the service time for data packets by routers, and notations S_1, S_2, S_3 and S_4 being presented for measuring the routing space in terms of required service time that is to be obtained for fault tolerance;
- c) $N(t) =$ capacity per routing node, representing the number of packets that reside in the router while waiting to receive the acknowledgement for transmitted packets;

Area \mathbf{Q} can be analyzed through the prism of service times of transmission tasks, providing in a gradual manner the deduction of space \mathbf{Q}' from which route \mathbf{q} will result (fig.3.21). The valences between performance relations and route choice \mathbf{q} are directly implied by the ability to transmit from communication equipment. Due to these dependencies, it turns out that from the following formula that's based on operations⁴¹, the temporal analysis can be observed on the performances that are to be obtained.

$$\frac{\lambda \cdot S}{Q} \rightarrow Q \quad (41)$$

By multiplying the arrival rate with the service times of routers and dividing the product with the available routing space \mathbf{Q} , an average routing pool/space can be obtained (41). The values are then compared with the initial transmission values, and the minimum values described by the protocol for making the deduction of space \mathbf{Q}' , after the removal of device options which cannot meet the required quality times.

The next experiment that will be presented was created for representing the operation of the proposed algorithm together with the analysis of interactions from communication media.

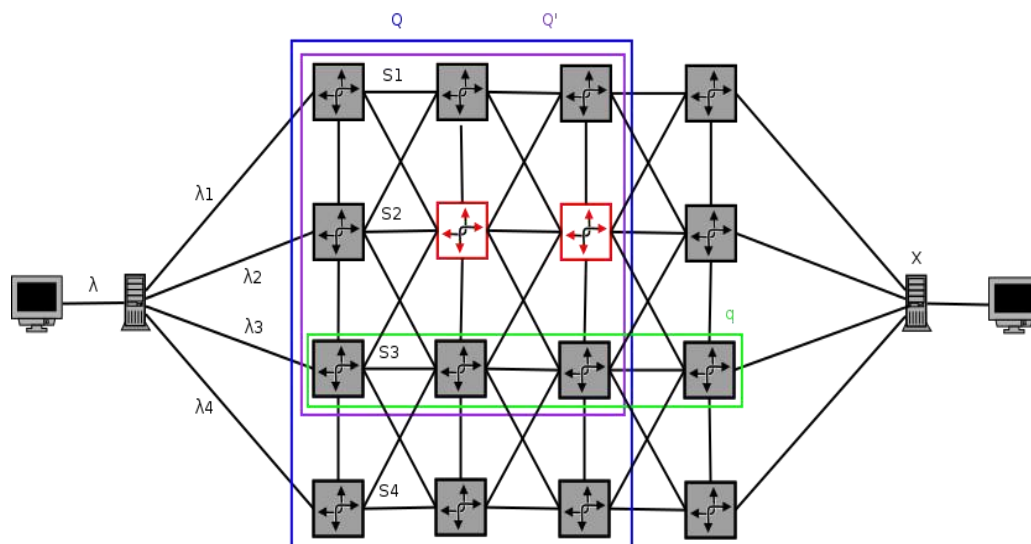


Figure 3.21 Selection space

In fig. 3.22, a routing pool is represented as having links that are evaluated in order to evenly distribute the data from the routing class of real-time sessions [ORZ16c]. This class is affected during

⁴¹ Correlation of arrival rate and service times with route selection space.

the performed simulations by a second dynamic data distribution through which the internet traffic flow is represented.

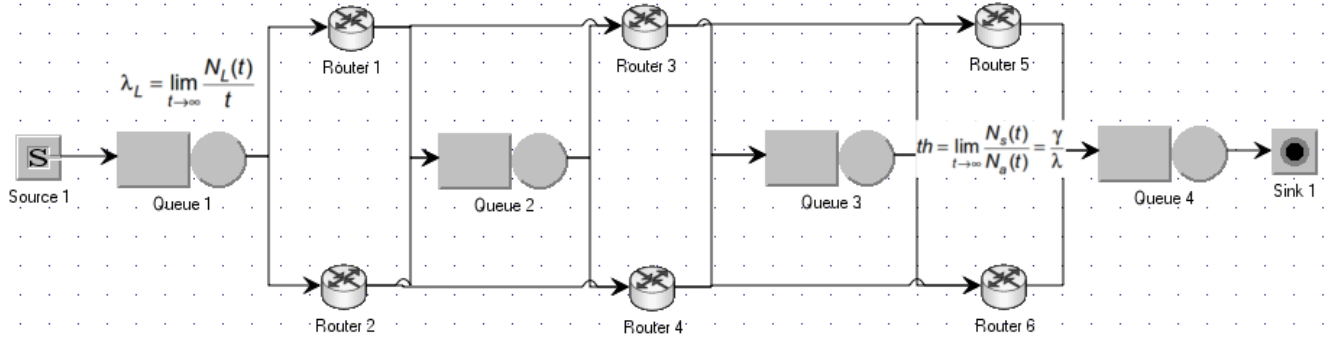


Figure 3.22 Stability analysis model

In graphs from fig. 3.23 the balance degree is shown as an action that can be achieved by the routing environment for the real-time session routing class and this is highlighted by two information distributions which are time-framed in the model (class 1 with 10 p/s, class 2 with 50 p/s).

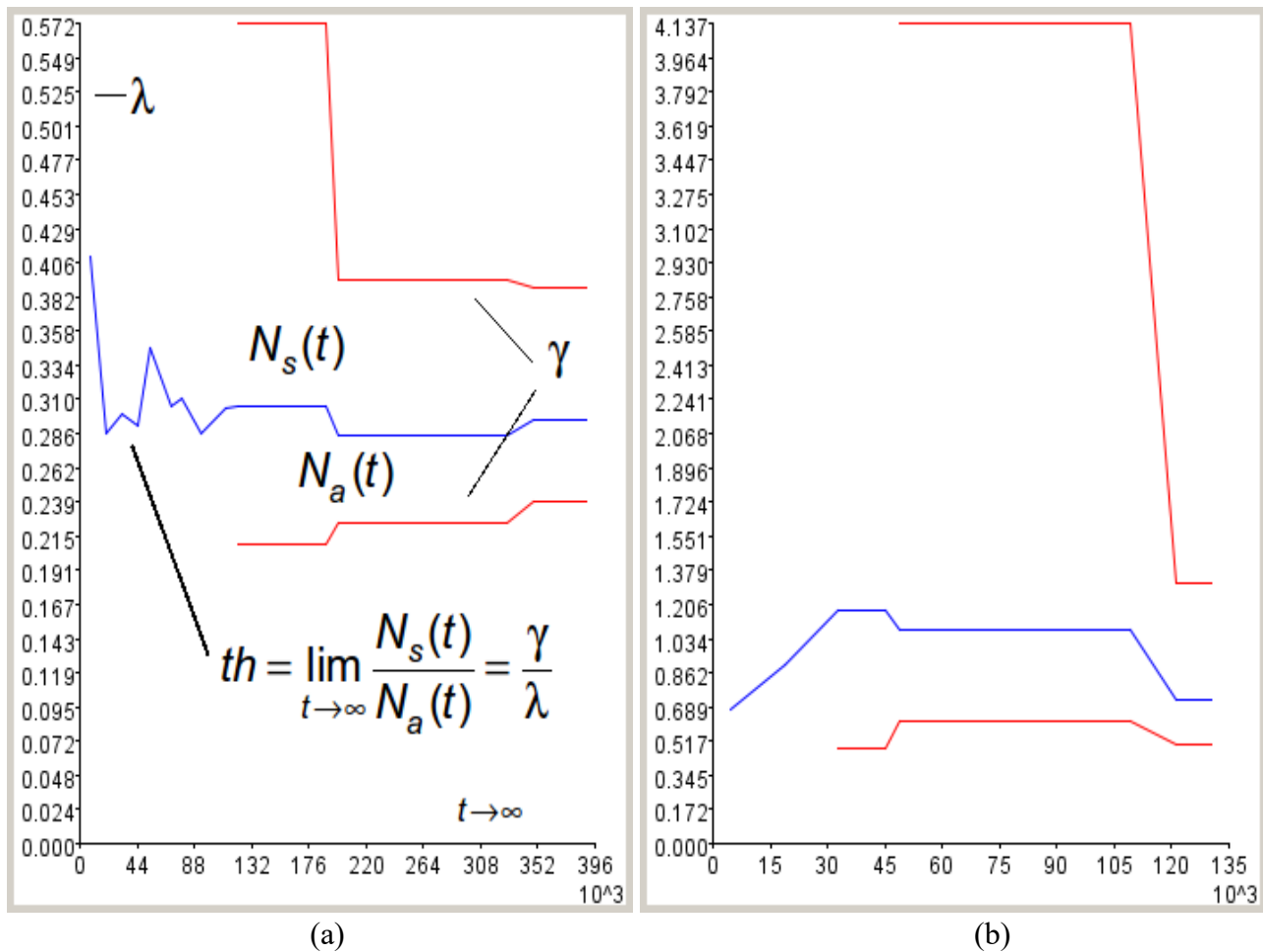


Figure 3.23 Variation of data traffic

In graph (a), the processing capacity of the environment indicates a maintained stability for data packets that are related to the first class, and in graph (b) the packet cancellation rate can be observed due to the increase in volume of packets related to data class 2. Slight variations in the performance of the data distribution from graph (b), indicate the allocation of routes for optimality by routers and switches, having the aim to maintain an overall stability for real-time processes. This fact results from relation (34) as being logical and deductible from the redundant routing methodology perspective⁴².

The created algorithm is a mathematical formulation whereby the data packet arrival rate is modeled in a subnet or contained region of a network. For it, I have mathematically derived the probability of stationary data packets from Little's law, derivation that is given by formula (42), and the notions described in the following paragraphs [IOA11].

$$\frac{\lambda_{ef} \cdot E[\tau] / s}{\frac{t' \cdot Q'}{T}} = s'' \quad (42)$$

s' is a result given by the calculation of the utilization degree whereby the actual arrival rate λ_{ef} is subjected to the magnitude of the transmission power $E[\tau]$ as being quantified over time s , and the temporal evaluation of the communication space Q' , with its adjacent time t' from neighboring segments that are framed in the global time T .

The evaluation of router performances is given by the metrics and performance policies that are implemented in routing devices per class. All these are a probabilistic evaluation of summing equal values into integer 1, for the first class (persistent route data), and least utilization of internet data for class 2. The persistent routing data class is set with an equal priority for each link of the routing environment, and the second class presents the search for unused routing regions that would not be subjected to the requirements of strict accuracy as that of real-time communications. In this way, the simulated routing model has the ability to interact for a beneficial purpose with a limited environment (immediately adjacent/neighbor), in order to provide good results for both real-time and additional data that's communicated via the Internet. I consider this a strong point of the proposed solution, because most of the solutions from the recent scientific studies on protocols, do not consider the negative effects on adjacent operations from routing networks and some lead to the cancellation of data packets if a rigid QoS requires it. It is not a benefit the cancellation of legitimate ICMP data packets that keep an HTTPS transmission with video content as active. Such packets may have an increased processing time, and a total higher delay of the ICMP cycle (round trip delay) that can be summed up correctly, without the loss of required and legitimate data packets.

To conclude this sub-chapter I present another experiment that I performed with the role of showing exactly this possibility. The used experimentation tool was also Java Modeling Tools and the simulation of discrete events, and through it I created an extended model of routing and operation (fig. 3.24).

⁴² The concept of redundancy is considered fundamental for achieving a high reliability of communication systems, being at the same time recognized in the scientific literature as a basic component of any method of communication that implies the mitigation of malfunctions.

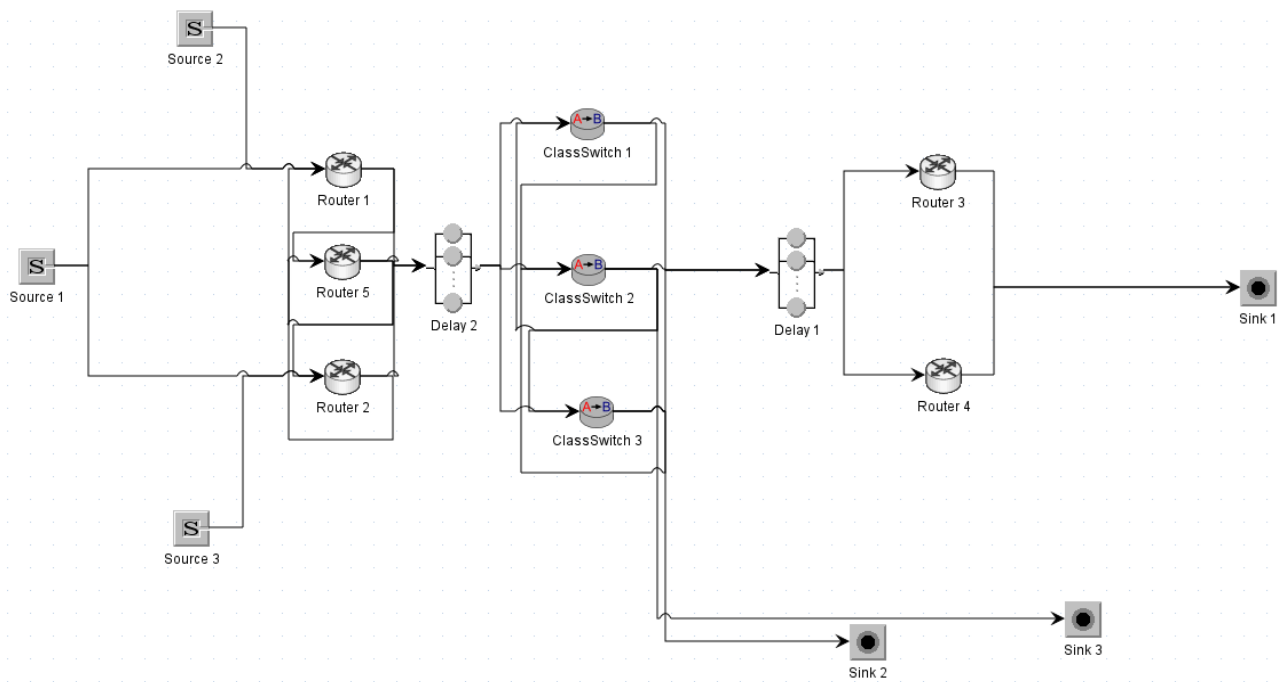


Figure 3.24 Dispersion model for the synchronization algorithm

The performance model is composed from a dispersion routing environment, having the most representative network phenomena embedded in the simulated network equipment. The focus is on routing class 1 that stands for the real-time data, while being accompanied in the model by a class 2 of adjacent internet traffic and a class 3 that's dedicated to disrupting the functionality of the entire routing environment in order to mimic a denial of service.

Being designated to represent the intersections of the synchronization algorithm at an appointed indict level that's destined to guide the reorientation of the persistent route, the chosen performance metrics were framed in the model in connotation with the logical use of the represented network equipment. These are 5 routers, 2 extended delay stations, 3 class switches and the sources and destinations of the data packets related to the three classes of traffic.

The probability of obtaining the desired results (rerouting to tolerate real-time intermediate transmission defects) from the represented model exists, but what must be understood from this study is that performance metrics are the elements that present the possibility of reorienting a transmission. The model from fig.3.24 is realistic enough to represent real-time transmitted data and planned network phenomena and events through the performed simulations.

The three sources for generating data traffic are of significant importance for the entire data flow that they represent in the model because classes 2 and 3 are recorded in the routing environment at various points indicating one or more communication paths. It follows that the action of each router is prone to stabilize the communication environment and does not involve the degradation of communications for any data packet. To clarify the previous statement, I mention that no router or network equipment in the world has directly imposed rules for canceling data packets, these being communicated on various routes if the equipment assembly allows it in terms of routing policies and service metrics.

In the graphs from fig. 3.25, the results obtained from the simulation of the model from fig. 3.24, highlight the statements from the beginning of the experiment presentation. The metrics used to present the simulation results are the response time given by the system for traffic class 1, respectively the processing capacity of the system for the same data class.

At the interaction level, it can be seen that the model contains the intersections necessary time frames needed to adjust the essential parameters of the sessions in real time, further resulting in the availability of interconnected systems to be optimized for the requirements of communication processes. I would like to highlight this fact because all states from Markov Chains give an attribute through which the travel time of the system or equipment can be viewed as a time window and/or space-time (if a larger region is traversed in a constant time interval) frame. These statements are represented by formula (43) that specifies the productivity of a computing system.

$$\gamma = \lim_{i \rightarrow 1} \frac{N_i(t)}{t} \quad (43)$$

In relation (43) γ represents the productivity of the system in completing the transmission requests N which are framed in well defined time intervals i and reported to t as an overall globally measured value.

With the model of fig.3.24 we have defined a wide range of technologies and methods for switching and routing data packets, these being applied to reorient a data transmission according to the indices defined in the model. Each quality indict is identified in the real world of packet transmissions as a parameter applied by the software protocol that's installed in the routing equipment. The parameters in question act as a limit or pattern of data transmission, with the aim of performing the routing algorithmics defined by the type or policy of routing.

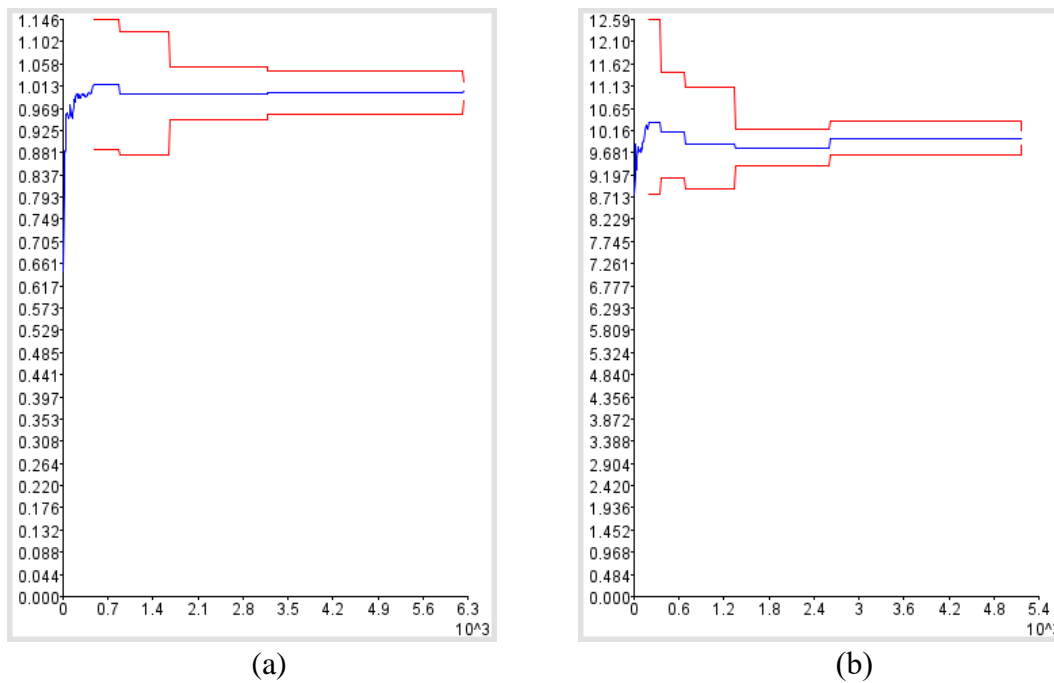


Figure 3.25 Obtained performances

Generally, the description in terms of capacity is complemented by Little's law [CHH08] in which data communications are modeled at the level of user demand and of computational process, not just at the level of chained communication that exists more or less as available.

Another set of simulations which I performed with the model from fig. 3.24 is a context created by reallocation traffic generated patterns for processing in the system. This generation pattern is valid for all three classes of data traffic in which for class 1 there are 10 p/s, in the second class 50 p/s and in the third class there were 1000 p/s. The generation of dynamic demands supports the interactional theory

that I claim, and this is mainly due to the fact that it reflects the dynamic contexts of reality from the Internet.

To be observed in graph (a) from fig. 3.26 is that the response time varies minimally for an extended communication environment while in graph (b) this is demonstrated by maintaining a balanced processing capacity for the exponential distribution class of the real-time sessions. Mathematically, minor variations can be described in terms of processing time between computing equipment.

In fig.3.1 we presented the mathematical formulation by which the time 't' can be obtained for some intermediate transmission defects. For the experiment illustrated in the graphs from figures 3.25 and 3.26 the probability that the time windows can be aligned is existent and rationally deductible. From this construct, I've found during the study that there are no represented limits to appear in each case, and which I can present for any context of error and/or network failure. Data communications support this statement because the dynamics of routing can degrade the communication time windows.

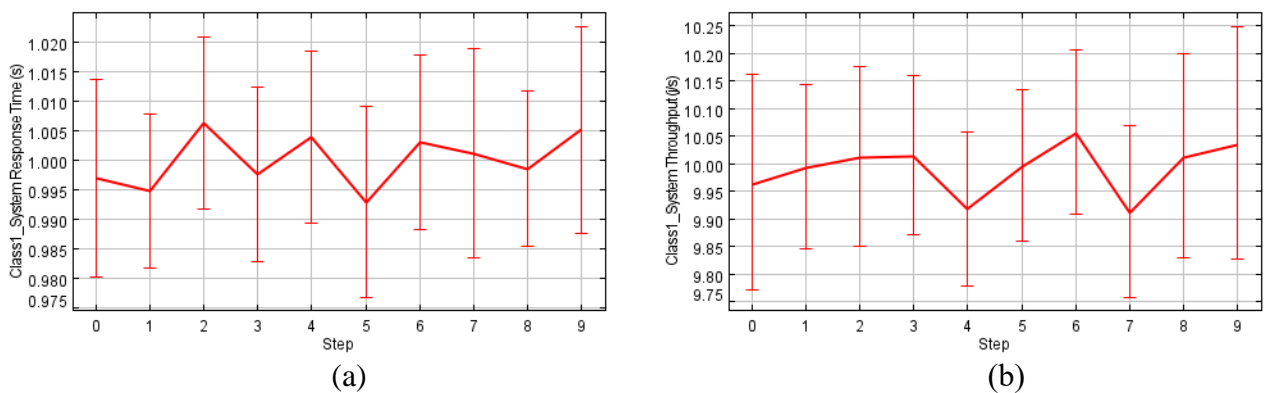


Figure 3.26 Analysis of interactions in a routing environment for the OSI session-level synchronization algorithm

The blocking probability from relation (38) specifies this directly [IOA11], and the applied routing protocols can vary from autonomous system to autonomous system. I will clarify these statements in the following sub-chapter to prove that computer networks have various peculiarities that can be organized to meet a beneficial purpose, but also to shape them with the current research directions.

$$p_b = B(a, s) = \Pr[N(t) = s] = p_s = \frac{a^s}{j!} / \sum_{j=0}^s \frac{a^j}{j!} \quad (38)$$

The results presented from the performed experiments are of indicative nature, and through them I described the limits and technological complexity through which the algorithm timing must run. The protocol proposal I make incorporates the synchronization algorithm with the role of managing similar values that can be given by a possible applicability in data transmissions. For this I included in the analysis, the dynamic generation of network tasks, a coordination of information traffic through algorithmic rerouting, and last but not least, I applied rules of probabilistic ordering of environments that run by adjusting performance parameters. We managed the performance parameters by imposing flow tracking only if the simulated equipment can meet the conditions to transmit based on time limits. In this way, the metrics that can form the communication time limit of a packet(wait time, response time, queue time), were also applied in the performance measurement process of a logical equipment that's able to tolerate overloads and network faults.

Conclusions for the Synchronization Algorithm Applicability

In this subchapter we presented how the proposed synchronization algorithm can be applied to tolerate defects of real-time routed OSI sessions. The performed simulations have as mathematical support the defined relations which were created in terms of the parameters that manipulate volumes of data packets. At the same time, these notions are used in the analysis of routing regions in order to find optimal routes for reorienting communications with qualitative time limits that are related to OSI sessions.

3.5 Technological Comparison

This sub-chapter presents the obtained results of the study. They are built in terms of their usefulness, and comparing them with existing solutions from the field of networking in order to mitigate intermediate faults for real-time transmitted sessions. The comparative analysis between the results obtained from applying the algorithm with the existing techniques for mitigating defects, is of a progressive nature, having the main objective to complete insufficiencies of logical data routing. Mainly, fault tolerance techniques of persistent routing have a backup route as available and active in the event of a fault. At research level and standardized development, world regulations on reliability also imply the provision of a third communication route to facilitate the redundant fault tolerance of defects that may be caused intentionally⁴³. These types of attacks can cause transmission defects for persistent routes (even considering backup routes as targets for information attacks), and are mainly carried out as DoS attacks on some network nodes found⁴⁴ to be vulnerable in the transmission process.

Communication through multiple routes is performed by certain network protocols that have as mechanism for fault tolerance the ability to create double traffic backup routes. Among the notable protocols from the study of real-time session level transmissions are MPLS, BGP, AS-AS, IS-IS and RSVP. These are described in the following listing for the context of dual traffic fault tolerant routing.

- a) MPLS: a protocol implemented with alternative communication links, having the purpose of mitigating defects for the main route that's creates for data transmissions. Doubled links are the only method able to apply fault tolerance and are considered unique, because MPLS is a special protocol through which different data formats are imposed for the packets that are communicated;
- b) BGP: being an implementation of rules for communication between networks, this type of protocol has at its disposal several means of communication between networks that are intended to be interconnected. It is a method through which communication distances are calculated, packets to be from the start transmitted through the internal routes considered the shortest, or depending on the type data protocol (ex. RTP, HTTPS, SSH, VPN), on the best routes found in the respective moment (with high reliability, sufficient bandwidth, service times as fast as possible) [DREAM12];
- c) AS - AS: at the level of communication between systems that are globally recognized as large networks (so far having around 65000 prefixes available to register them), there are the communications between autonomous systems which are made under the coordination of protocol rules that are applied as flow management policies [HUS08]. Autonomous system prefixes enable path lengths and prefix compression, and sum-ups for searches that are made

⁴³ Through targeted attacks on sessions routed in real time.

⁴⁴ By analyzing the TTL fields and the TCP sequence number, as well as the type of packet in a transient state of agreement.

based on IP addresses subnets. This allows the rerouting of globally traversing data through different regions that are part of other ASes;

- d) IS - IS: because networks are interconnected, this protocol was created to specify by distance vectors the extension of each network to be interconnected with another, while also providing useful information with regard to link multitude and number of hops;
- e) RSVP: an implementation through which resources are reserved as needed by routing processes, this protocol being mainly focused on using the required bandwidth and prioritizing transmissions which can need physical capacity, as well as metrics for fault tolerance with dual routes;

The protocols just mentioned are useful in applying fault mitigation and tolerance through dual paths, but through them the number of requests for resources can grow significantly. This is unlikely to appear in the context of the proposed synchronization algorithm because faults tolerance is accomplished with the runtime of communication devices, and not by imposition a constant reservation of available resources.

$$D_x = [D_x(y):y \in N] \quad (44)$$

In relation (44), the distance vector \mathbf{D} is formulated by the authors of [PRI11] as a logical interdependence of equipment that must always choose the shortest path between two points \mathbf{x} and \mathbf{y} . Relation (45) completes this criterion [PRI11] through the path vector \mathbf{v} , where the trajectory of the packets sent by \mathbf{x} are always in the vicinity of the segments with a secondary time cost compared to that of the shortest path.

$$D_v = [D_v(y):y \in N] \quad (45)$$

Real-time communication sessions include a wide range of services and technologies, all forming computing processes in terms of routing, processes which require high quality and an increased attention from the transmitting equipment [MOD13]. For this reason I mention that the experiments presented in this chapter, have had the role to represent the throughput and response times afferent to data packets that were transmitted through abstract routing equipment. This methodology is also applied and sustained in the scientific world, an example being the study of [ARF14], where the authors experimented in a similar manner. In general, we performed simulations that highlighted dynamic routing contexts, comparable to works in the field like that of the authors from [GRU13]. These can be found in specialized publications and in existing technical implementations in the form of generic networking as mentioned in [CIA11], having the goal to forward data packets between their interconnected nodes.

In tab. 3.3 I made a functional comparison between the transmission error correcting solution of the authors from [GRU13], and the claimed contributions of this thesis. The comparison was made in order to highlight the current parameterization possibilities that are intended to mitigate various anomalies of real-time transmissions.

From the network organization point of view, it is known that interconnected systems and the internet do not have a topology or a range of topologies that can be recognized as self standing/definitory for global communications. The most realistic way to organize and create simulations was to present contexts that were generated at random [WIL14]. This is done with distributions that may have increased arrival rates for modeling volumes of tasks through policies, and by using routing algorithms that are applied by current research such as [CON14].

Characteristic	Profiled RTP [GRU13]	Interactional Analysis and Synchronization Algorithm
Fault tolerance	Only by retransmitting data on the same routing segments, mitigating only disruptive effects of minor anomalies.	High, and applicable by retransmission of data on additional segments. A fault can occur for any type of hardware and/or software, network fault.
Traffic cost	Medium, the solution being based on bidirectional flows in the RTP session.	Low, because it only requires data transmission from a data session.
Update cost	High, the environment depending on the routing pool.	Low, because the routing algorithm makes use of existing data links as available.
Protocol established agreement	Complex, and with many sub-tasks and processes that need to be performed.	Only that of the initial agreement, being also complex and depending on the tasks to be performed.
Execution speed	Slow, as processing takes time and has a high packet overhead.	Very fast, because it requires routing within specified time limits and with minimal error margins to tolerate and reroute data.
Error correction	Applied in a multitude of additional software mechanisms.	Existing, with normal TCP applicability.

Table 3.3 Comparison of solutions with fault tolerance of real-time sessions

In tab. 3.4 I have created a comparison between the work of the authors from [CON14] and the proposed solution, because any communication protocol is dependent on existing routing possibilities. This comparison highlights concisely the ability of the synchronization algorithm to be applied with increased benefits over the limiting constraints of the solution from [CON14].

Characteristic	Multiple Local Mobility Anchors [CON14]	Synchronization Algorithm and Interactional Analysis
Data routing	Existing, but highly dependent on the reconfiguration dynamics of the service operator.	Existing, the solution being dedicated to rerouting packets if adjacent segments can meet time-based performance limits.
Connection orientation	Regardless of the used data service.	Intended exclusively for these types of communications.
Processing cost	High, because it requires centralized coordination of the routing environment.	Low, because it just depends on the action of routers that are adjacent to the disrupted equipment.
Central dependencies	High, because routes are always directing to the nodes and access points needed for data forwarding.	Non-existent for the environment, the protocol requiring only the retransmission of data if the performance criteria are met.
Network signaling	Redundant, and with many network advertisements to signal the property of dynamic reorganization of the environment.	Only in the region of the incident and with a request to pick up and forward packets to adjacent equipment.

Table 3.4 Analysis between the solutions from [CON14] and the personal solutions

In this study I was focused on presenting the performances that can be achieved in order to ensure stable real-time transmissions, and the simulations I undertook were developed and analyzed with the usage of performance metrics. Each metric has its applicability to the presented context of the transmission model, analyzing the performance of communication trajectories according to the volume

of generated traffic and the available capacity of the simulated networks. I also mention that improving real-time systems as presented by the authors of [BUR97], implies fault isolation and tolerance as logical devices for analyzing some malfunctions. For real-time communications, the delimitation between these two methods is made only at the deepest level of operation with performance parameters. As an example, I state that rerouting on another path can be a software topological isolation from faulty subnets, while at the same time being able to represent and tolerate disturbances in case the routing media consider so (even with the smallest weight) a subnet with multiple recorded errors in the history log.

Further information on fault tolerance can be found in [HAS10] and [IQB13], where the degree of functional redundancy is presented to be achievable for resources of different types (processors, hard drives, inter-process buses, controllers, network interfaces), and provides a comprehensive description of the overview for which various mathematical formalisms are specified.

Research in computer networks has always included a possibility to describe the phenomena that is to be produced, and given the fact that the volume of information and the degree of technological complexity has increased significantly in the last 20 years, experimental devices branched into several areas where software and hardware programs prove to be clear. That's why for this thesis I explained the hardware foundation from a theoretical and logical point of view, and I also described the software usage while benefiting from the simulation of transient data phenomena that can be represented.

In some cases we have undertaken unique simulations with specific metrics, such as utilization degree and throughput, and in other contexts we created random scenarios (ex. what-if) which are presented in graphs in the form of the result of 10 different simulations for that one model, but with various delay times or with gradually increased processing volumes.

In the next performed experiment, I present the data packet traversal through a dynamic routing environment (fig.3.27), an experiment that is complemented by the simulation of a larger network (fig.3.28) which applies routing according to the shortest paths between source and destination and with the shortest wait times. The analysis from the model of fig. 3.27 is focused on the description of transmission reorientation possibilities, with segments available to choose as alternate paths in order to continue a disrupted transmission. The context is expressed as having three routes to send the data packets to the destination, and because routers are elements that have a high processing power, their ability to present good performances to communication protocols is deductible and observable for the real-time transmission reorientation.

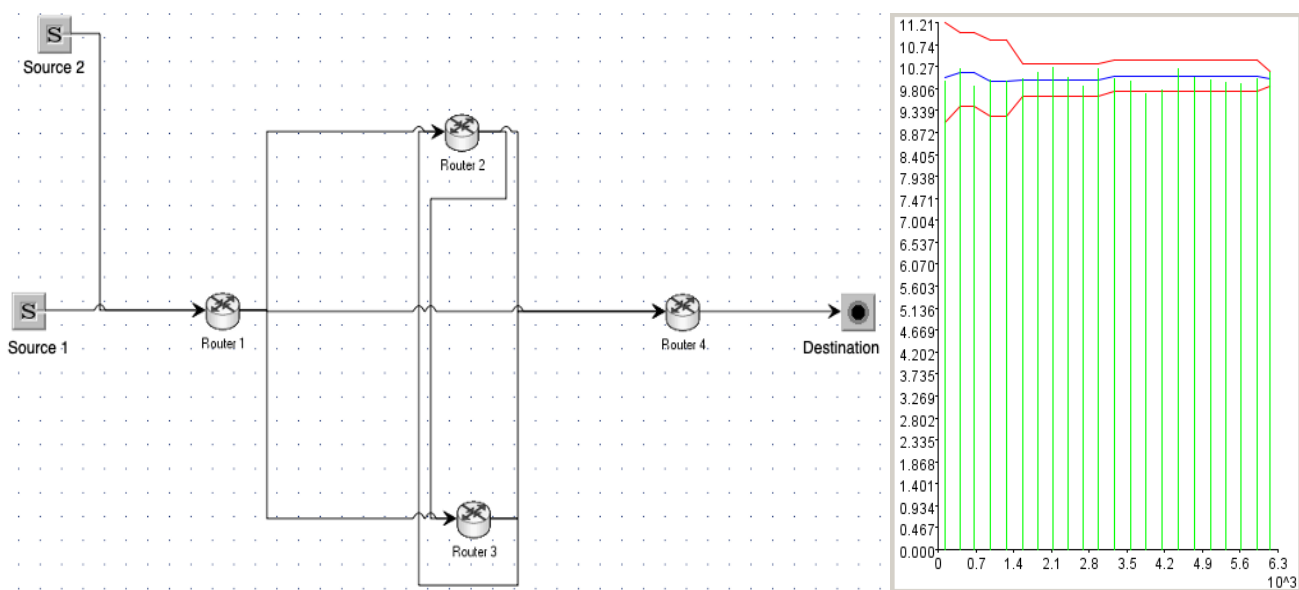


Figure 3.27 Dynamic model for opening the shortest path

Attached to the model of fig. 3.27 is the stability graph of the communication process where real-time scaling is of the order of 10 to the third power (10^3) to represent real-world scenarios.

In the real world of the Internet, interconnected systems and networks are dynamic, and variations of their traffic is rarely predictable even with the most accurate service estimates. Through the probabilistic models that were presented in this study, the results that can be obtained from the synchronization algorithm and the concept of interaction is that considerations can be made on performances of computer networks, these having as basis the actions, reactions and effects of network phenomena. It is well known throughout the scientific world that the application of a protocol, rule or equipment, may be beneficial or deficient in a context, depending on the correctness of the functional analysis performed for the in-cause communication medium. As an author, I synthesized these abilities and understandings for transmissions of data, with the use of explanatory notes for the various effects that may exist in computer networks. These are vast, being the object of the partial action of a performance parameter or a data carrying characteristic which does not fall entirely within the scope of real-time communications, but which I included in the conducted simulations through additional distribution classes.

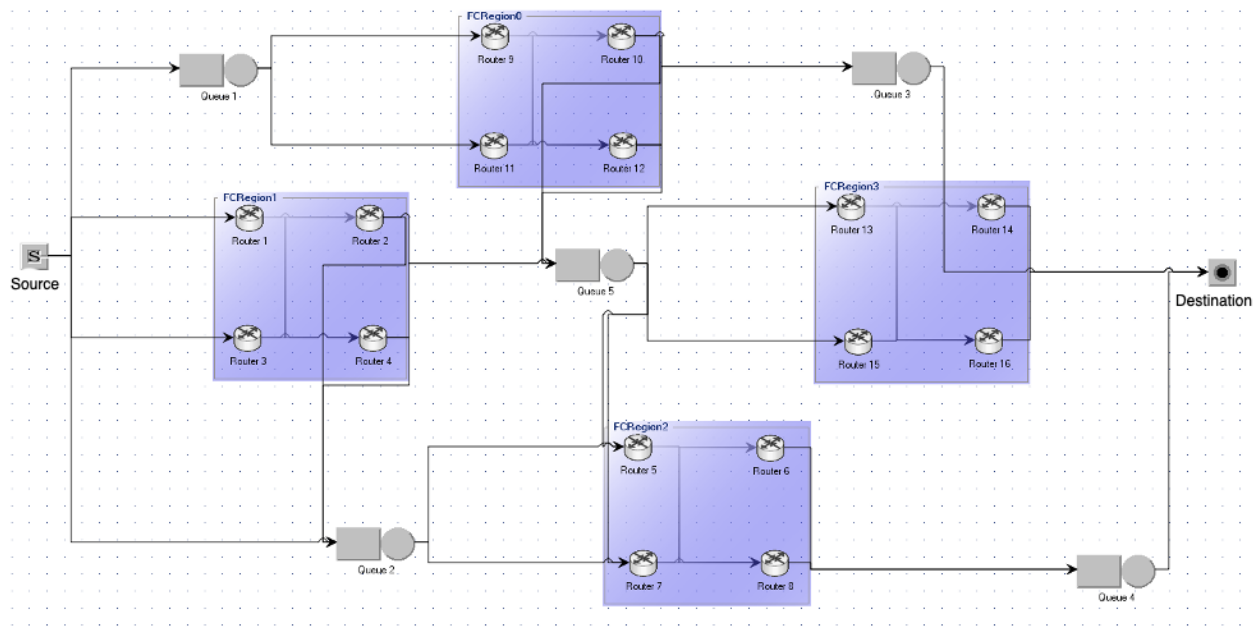


Figure 3.28 Extended operating model

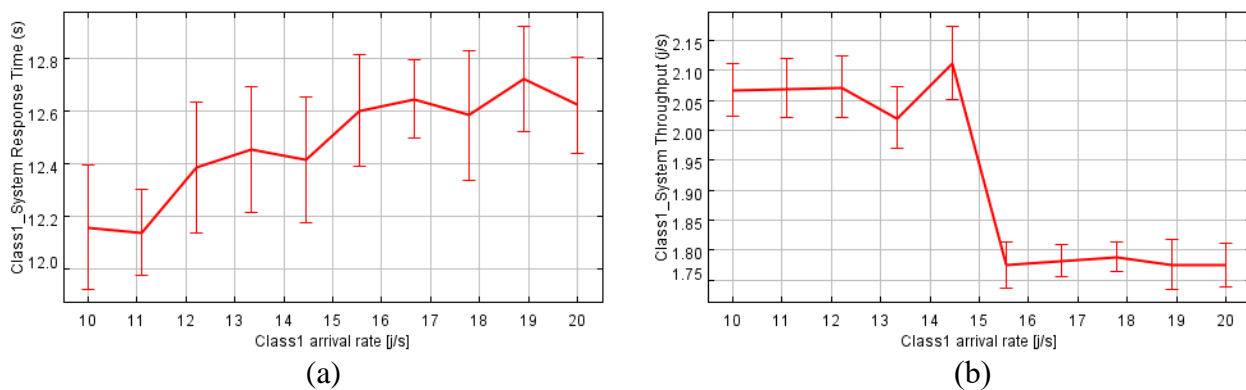


Figure 3.29 Extended performance model

I created performance evaluation models with elements based on the possibility to mimic data traffic, presenting through the identified sources the generation points of packets data, while routers have the role to perform the routing itself. The routers from the simulated models are also component identification points, which form the smooth running of communication protocols, simultaneously having as simulation characteristics the prescription of some norms of algorithmic targeting for fluctuating data. I mention algorithmic targeting, because the instructions that show how the data packets are transmitted, highlight the program through which the transmission logic can be implemented as an algorithm, and the time in which the in-cause instructions are executed.

In networks that are chaotically organized and have a hybrid architecture(fig. 3.28 composed from several topologies and architectures) or are a mixture of topologies [FAT14], protocols that perform real-time transmissions at the session level can provide quite low performances, which can be seen from the graphs presented in fig.3.29. Response times can increase in an alarming way(fig.3.29a), and the throughput capacity of the network can be substantially degraded(fig.3.29b), resulting in a lack of quality and integrity guarantee for persistent route transmissions. These degrading effects are represented mathematically in the next two relations (46 and 47) to justify the central dependency metrics when compared to the collaboration of the whole set of technologies.

Being representations of real world contexts, functional cases such as these are analyzed by the packet loss rate P_L and productivity of the communication system p as presented by the authors of [IOA11]. The internet and interconnected computer networks are all used in a variable way, having a behavior which often reflects disruptions and which for real-time transmissions are the causes of process interruptions.

$$P_L = \frac{p^2(2-p)}{2(1-p)} \left[\frac{p^2}{2(1-p)^2} \right]^{B_i} \quad (46)$$

$$P_L \vee \text{crossbar} = 1 - \frac{1-e^{-p}}{p} \quad (47)$$

The probabilistic limitation from relations (46) and (47) is given by the processing whole 2 of the system, or 1 of the subsystem on which the analysis P_L is operated. Complete/whole processing represents for existing systems show the maximum/upper processing limit of the transmission unit in question, and is a reference point for any network logic based on quality metrics.

The models created in fig. 3.27 and fig. 3.28 have the role of fulfilling a performance evaluation between environments that contain opportunities to double data traffic in order to tolerate defects, and to present the solution of rerouting by choosing an alternate segment. This understanding is essential to knowing how fault tolerance can be ensured by communication media. The routes allocated for the purpose just mentioned are closely related to the applicability degree of a means for tolerating intermediate as well as global defects. In table 3.5 I present a comparison between the synchronization algorithm solution with the solution of dual traffic from the point view of existing abilities from transmission carriers.

Certain forms of network identification, as well as those made through the prism of topologies or through specific positioning of routers in systems, are not represented in the context of this study because the transmission must be able to communicate data between entities requesting persistent routes. Observable from fig. 3.28 is the modality of comprising a large number of routing equipment which can transmit data. But, without having such a method to guide the operating process in terms of necessary parameters [32] as those of the synchronization algorithm, there may result cases such as those from the graphs related to fig. 3.29.

Characteristic	Transmission Reorientation with the use of the Synchronization Algorithm	Applicability of Doubled or Tripled Traffic Paths
Protocol	Efficient, because real-time communication protocols would only need argumentation based on time criteria in order to reorient the transmission.	Inaccurate and with multiple resource requirements which consist of multi-path bandwidth and constant maintenance of additional data streams.
Dynamics	Possible because only certain routing equipment should be used.	High dependencies on the volume of data traffic.
Confirmation of data packets	Dependency on the applicability of the synchronization algorithm because the data packets are kept in the memories of routers for their retransmission on the selected new routes.	Necessary in all stages of communication, raising the time of defects through the backup routes because packets must be identified from which the transmission to the recipient must be resumed (until the moment of entry into use, the duplicate data from the backup routes being canceled by the software interface of the protocol).
The trajectory of the communication route	It can be allocated on request and by evaluation based on performance criteria.	It must be constantly the same, from the opening of the connection for all transmission routes, both active and backup.
Topological integration	It can be set as basis for the transmission flow in accordance with the orientated graphs of environments.	It is necessary to maintain the route through the existing constraints of the networks, having as fixed limits only the performances obtained at the time of route creation.

Table 3.5 Comparison through communication skills

Continuing the development of experiments that were defined to prove the applicability of the proposed synchronization algorithm is a new model that I represented in the illustration from fig. 3.30. The model is defined by two classes of data traffic, 12 routing devices represented as the queue nodes, and the sources and destinations of both distributed classes of data. The data class which I analyzed has as a point of generation of packets source 1 and as destination the node named in fig. 3.30 "Traffic class 1 destination". The routing policies of the model are the shortest response time for class 1 and the fastest service for class 2 of data packets. The arrival rate of data packets is 10/s for class 1, and 20/s for class 2, these being transmitted in a finite capacity environment.

In the performance evaluation model illustrated in fig. 3.30, I used the entire system response time metrics and data packet cancellation rate. The graphs from fig. 3.31 show the response time and the cancellation rate of packets from finite capacity regions, in which the possibility of fault tolerance is performed.

Response time is found in time intervals that can be considered optimal to mitigate the defects of some intermediate nodes(fig. 3.31a), fact supported by the region of finite capacity because the data distribution did not show a significant variation during the 10 performed what-if simulations. They have had the service time increased four times at the node queue 6 for the data class 1 as a negative effect, resulting in a very low packet cancellation rate and which can be considered the existent error margin from any type of network due to its constant value from fig. 3.31b.

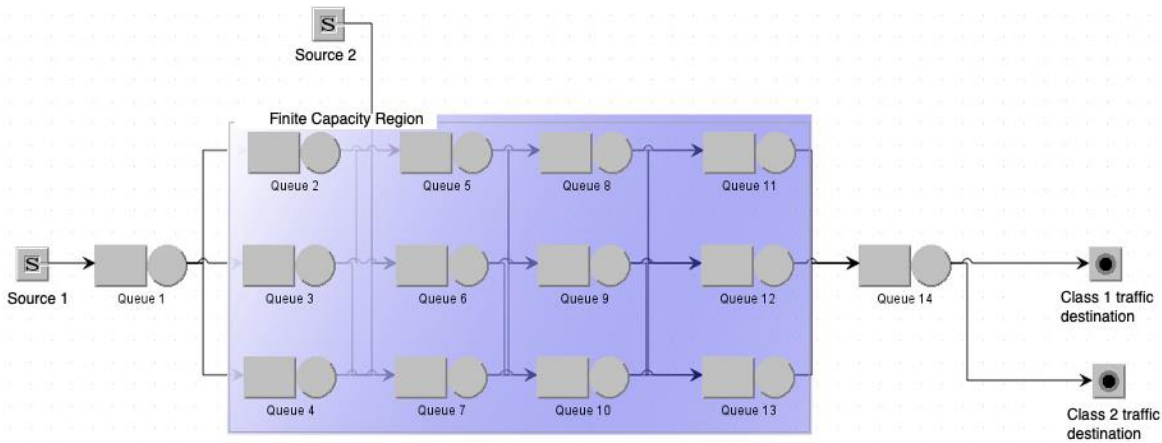


Figure 3.30 Persistent routing model

The error exemplification is comparable to the work of the authors from [GRU13], [KHA13] and [VER11], because the mitigation of an intermediate defect without using dual traffic links, presents in the undertaken study, the response times that vary greatly and that cannot ensure proper operation for transmissions in real time.

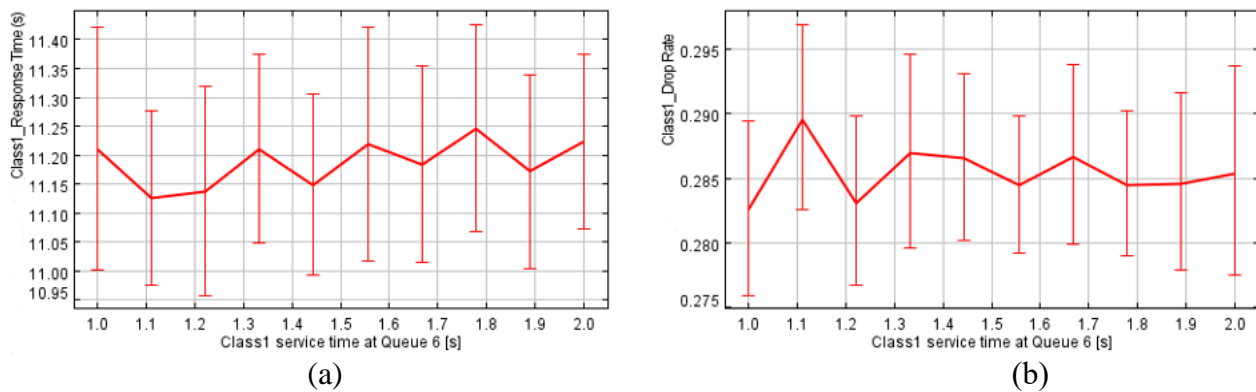


Figure 3.31 Response time (a) and packet cancellation rate (b)

In this subchapter we have developed a comparative study between the various possibilities to tolerate communication defects that exist in the real world. The solution I propose have the role of tolerating intermediate network faults on a single communication route, involving lower communication costs than mechanisms which imply doubled or tripled routes for them to be considered reliable.

Scientifically, I state that the synchronization algorithm and the concept of interaction (the main contributions) provide additional guidance and organization for the correct use of network resources, as well as the role of assigning the reliability property for real-time sessions. This is a general quality metric through which I also presented the usefulness of parameter adjustment by using performance indices that can tune real-time transmission processes.

Because data transitions require certain properties to be met, the states and attributes involved were also analyzed. This was accomplished by simulating transmissions through an intersecting environment in terms of performance and logical parameters. I created the simulation environment as a dedicated view for route selections after the routing algorithm performed the performance assessment through the prism of the indicts set in the model.

As example of achievable parallelism, another experiment is presented in the model from fig. 3.32, model which consists of the source and destination of data packets, two traffic timing stations(queue 1 and 2 by which the variation of internet traffic can be simulated), and 8 routers connected in rows of 4 each.

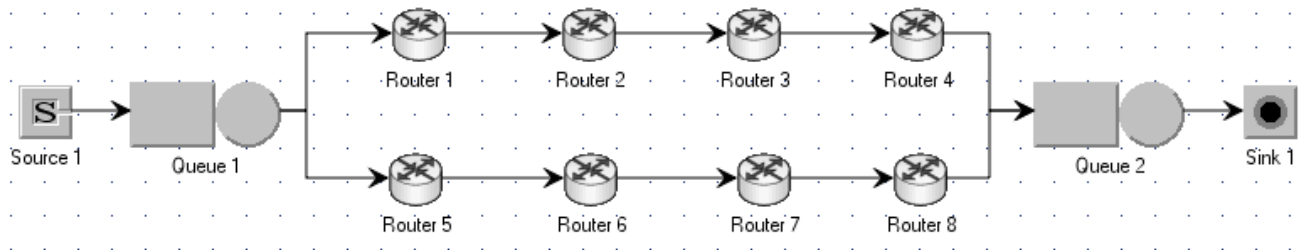


Figure 3.32 Parallel transmission model

Having a uniform data flow (fig. 3.33), the performance of the simulated transmissions can be considered as evenly distributed in terms of route selections for OSI sessions.

In the paper [ORZ16c], I wanted to present these time issues of route performance computations on adjacent segments, because the cost of routing and update from routing tables have an increasing impact on packet data transmissions. For this, the model was extended(fig. 3.34), being practically a duplicated environment of the model in fig. 3.32, in terms of route selection space and having the same parameters set for the additional segments.

From this model I deduced that the number of segments has a low importance in terms of updating routing tables. This importance is complemented by similar communication times that can be seen in fig. 3.35, from which I concluded that real-time rerouting can take place, if the required resources are available on at least one adjacent data link.

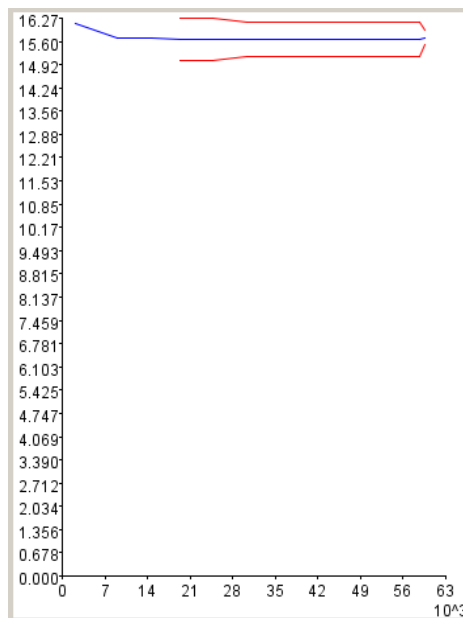


Figure 3.33 Balanced distribution of data traffic

The experiments represented in figures 3.32 and 3.34 are comparable to those of the authors from [ZHA12], where the studied type of network, overlay(overlapping), used link adjustment with related logics for optimality.

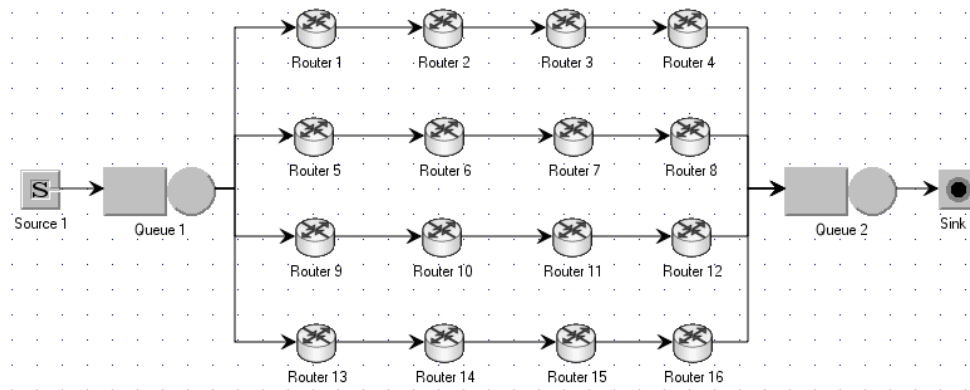


Figure 3.34 Extensive routing space

The study from [ZHA12] is also focused on optimization and distribution of tasks in order to achieve a global optimum in terms of stability, but essentially the overlaying networks type depends on the common logical parameters by which they are created in the transmission media. The logical links analyzed in [ZHA12] lead to structures based on K-minimum-spanning-tree(KMST), but depend exclusively on the QoS performance of the transmission medium. This comparison was made because persistent routes can be seen as superior transmissions, acting OSI sessions with a high degree of transparency towards end users.

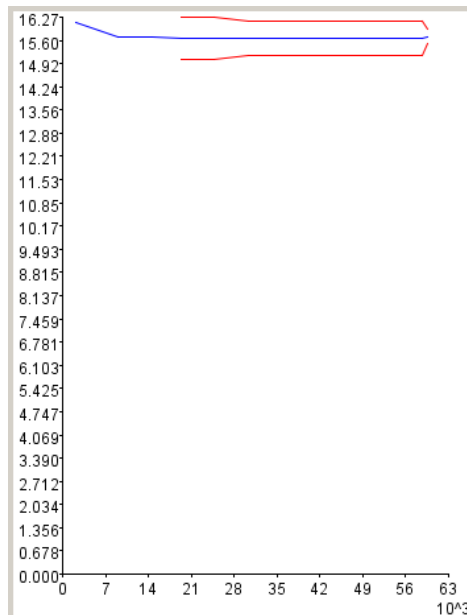


Figure 3.35 Identical performances as of the model from fig. 3.31

Conclusions for the Compared Technologies

In subchapter 3.5, a technological comparison between the existing solutions that were identified in the profile literature and the personal contributions that are claimed was presented. The benefits of the synchronization algorithm and the concept of interaction are clearly specified, as they are mainly focused on using only the network resources that are immediately needed to tolerate intermediate routing defects.

The mathematical formulas presented indicate the benchmarks through which real-time rerouting can be operated, implying also the characteristic of reliable technology to be assigned by reliable indicators and probabilistic protocol analysis metrics.

IV. CONCLUSIONS

This chapter is dedicated towards presenting the conclusions which I consider auspicious for the study I have undertaken on routing technologies that run real-time communication sessions. Simultaneously, I will also describe succinctly the developed personal contributions together with their usefulness in the approached topic, as well as the future research directions for this type of real-time OSI session level transmissions.

The main contributions that I claim are the following:

- Integrating the concept of Interaction in the OSI model;
- A synchronization algorithm made for tolerating intermediate defects of persistently routed session level transmissions;
- A protocol proposal in which the execution steps of the synchronization algorithm can be applied to meet the purpose of fault tolerance for real-time communications;

The ideas outlined above, involve a theoretical comprehensive consideration on the technological ensemble through which persistent routing is performed, allowing the attribution of the reliable communication characteristic. Ensuring a real-time communication process to be part of reliability and dependability values, is given by the analysis on routing resources through which disruptive effects are mitigated and routing is maintained as functional after the usage of routes that were selected through performance terms.

During the current state of the art research documentation(Chapter 2), I presented items of logic from Markov Chains and Queue Theory that led to the analysis of persistent routes and the formulation of the concept of Interaction. I mentioned them in terms of their usefulness in modeling the performances of real-time network transmissions, being highlighted mainly by their analytical possibilities. Each possibility consists of the data routing behavior, by mapping effects as transmission events(e. Markov Chains states) in limited time intervals which become observable(ex. Queues).

The overall analysis methodology formed by the existing technology is also presented in the introduction. Due to the fact that it is a necessary process for guaranteeing performance in the operation of communication media, we analyzed persistent routing through terms of functional analysis. These were described informally, because each method includes measurement and control metrics that underlie the description of the performance of communication protocols. That's how I argument with the use of existing units, indices and parameters, the validation method of the performed study, namely the simulation of data transmissions in an abstract manner, which correspond to qualitative requirements of OSI layer sessions.

Performance evaluation models were created in the form of dynamic simulation contexts, being the only possibility of affordable experimentation from this study. The representation of the persistent routing problem is described by mentions related to the performance aspects that lead to its occurrence. Disruptive effects were explained by using examples that were gradually analyzed with the methods of organizing communication networks, in which transmission protocols of real-time type were applied.

Chapter II presented organizational forms for networks and technologies through which persistent routing is created, with examples and arguments added for the complex whole that forms the real-time communication process. Functional explanations and presentations were mentioned, because real-time transmissions are routed through components that are time-framed, and set in various communication topologies and graphs. Transmission processes are in turn created by the optimal cooperation of the assembly elements which forms them.

The proposed solutions are presented in Chapter III, having as a foundation the analysis based on queue theory for data flow simulations. Data flows are parameterized depending on the routing contexts

variant, having a significant role in the process of deducing the usefulness of time-based performance metrics.

The transmission sessions were divided into process analysis, with the wide possibilities of routing, and into networks analysis, having the operation of routing equipment at the center of attention both for the presentation of the persistent routing problem and for the representation the proposed solution.

Being a solution that must be adapted to the field of communication networks and in particular, to the international norms applied at a global level, the presentation of the concept of interaction requires the analysis and troubleshooting of OSI session-level malfunctions through the synchronization algorithm. It is operated by performance metrics which are in accordance with the protocol rules that form transmissions. The protocol ruleset was created and analyzed both by technical comparisons and by concrete analyzes of unitary equipment and networking environments. They are described in the study as a necessary criterion in fulfilling fault tolerance of real-time failures.

Any communication protocol makes use of functional criteria for both guaranteed transmissions in terms of quality, as well as for communications based on retransmission algorithmic efforts. In this way, the operating criteria were established by using routing indicatives that can be optimized with the desired parametric specification.

The synchronization algorithm is described as an applicable possibility to persistent routes from sessions, having the interactions between the transmission components as it's creational elements.

The technical problem in question was highlighted in a deductible manner, with generalized and specialized presentations(routing cases), being based on current studies that have property fundamentals met(scalability, dynamics, heterogeneity). I insisted on these features to be part of the thesis because my personal ideas allow in turn for proposed solutions to have a real and efficient trasposition in the environments of real world transmission. All the represented elements have had the role of clarifying the dysfunctions between media components, facilitating through performance metrics (which provided adjustable quality indices) the deduction of contributions in order to meet the fault tolerance of persistent routes on a single route.

This document is based on a concise documentation from the scientific literature, being complemented by experiments and logical approaches offered by simulation techniques from Queue Theory and Markov Chains.

Routing equipment is making more and more use of concepts and theory fundamentals that have always been the basis of research on properties like reliability, stability, availability and robustness of data packet transmissions.

Data session communications are made available in interconnected environments through the platform paradigm, paradigm that offers through transparency and heterogeneity a complex functional development.

Routing protocols are created in co-notation with routed protocols because the limits of performance that are to be achieved by the processing nodes, also need to be uniform with the transmission segments that carry data to autonomous regions and systems. At the level of programmability, the code of network programs requires the creation of uniform transitions for data traffic, allowing at the same time an optimization of information flows, according to the case and context [YEM96].

It is known in the scientific world that problems in routing environments are non-existent when resources are available both in terms of physical(hardware) as well as logical(software) constructs. Hence, the reappearance of the problem of persistent routing required the creation of a new specialized analysis method for the cases of unique network problems [YOS12], or a generalized method for the cases in which there exist infrastructure norms that can't tolerate disruptive propagated effects [YOU11].

Real-time communications researchers all use limited simulation programs or test networks. These are nothing more than tools used for creating specialized or general contexts which are a means to

analyze and understand the problems, ideas, questions and abilities that are proposed as a goal to be fulfilled.

All the mentions of the study are sustained by their publication as scientific articles in conferences and journals such as INES 2016 and 2017, ISECT 2014, 2016, 2018, CINTI 2016, SACI 2013, 2014 and 2015, SOFA 2014, SISY 2014 and 2017, etc. . The articles in question validate the study I undertook, because each experiment presented in Chapter III was accepted by the scientific community both in terms of originality and mentions for improving the field of computer networks. The articles published so far, were either in events or in scientific journals, being listed below, to introduced a highlight on the submitted doctoral work.

- 1) S.N. Orzen, L. Kovacs, Routing Performance and Continuous Session Reliability, Acta Polytechnica Hungarica, DOI: 10.12700/APH.18.6.2021.6.2, ISSN 1785-8860, 2021;
- 2) S.N. Orzen, L. Kovacs, Internet Time as Virtual Time for Real-Time Session Routing, 2020 IEEE 24th International Conference on Intelligent Engineering Systems (INES), Reykjavik, Iceland, DOI: 10.1109/INES49302.2020.9147175, ISBN: 978-1-7281-1059-2, 2020;
- 3) S.N. Orzen, M.Stratulat, Performance Queues for Fault Tolerant Sessions, 2018 International Symposium on Electronics and Telecommunications (ISETC), Timisoara, Romania, DOI: 10.1109/ISETC.2018.8583983, ISBN: 978-1-5386-5925-0, 2018;
- 4) S.N. Orzen, S. Babii, Network Events in the Dynamic Selection of Real-Time Session Fault Tolerant Routes, 2017 IEEE 21st International Conference on Intelligent Engineering Systems (INES), Larnaca, Cyprus, DOI: 10.1109/INES.2017.8118574, ISBN:978-1-4799-7678-2, 2018;
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- 6) S.N. Orzen, M. Stratulat, S. Babii, C. Cosovan, Routing Tables as Big Data Searchable Structures for Achieving Real-Time Session Fault Tolerant Rerouting, 2016 IEEE 17th International Symposium on Computational Intelligence and Informatics (CINTI), Budapest, Hungary, DOI: 10.1109/CINTI.2016.7846415, ISBN:978-1-5090-3909-8, 2016;
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4.1 Contributions – Thesis Groups

The goal I set to myself during the study was to make a contribution and improvement in the field of computer networks, and I have achieved this through the usage of the Java Modeling Tools simulation stack. With this tool I created simulation models that can represent real-world operational cases.

I have also performed a rigorous documentation from the scientific literature, to find the necessary information for the integration of real-time communication technology at the session level of the OSI model.

For this I presented the current state of the art research for real-time communications by using persistent routes, a documentation through which the theoretical and practical directions for the development of data transmission systems was clarified. At the same time, through the current state of the art research, I identified the performance metrics that are essential for the analysis of transmission routes.

The own contributions that I mention to be original and authentic, represent the personal ideas I have developed to propose useful solutions for solving the problem of persistent real-time routing, respectively for analyzing the malfunctions between real-time technologies. These are presented in the following subsections in two thesis groups.

4.1.1 Thesis Group 1 (Representation of the Problem)

I have defined a method for recognizing and representing the persistent routing problem in real-time with linked actions that clarify the modeling of interactions between interconnected components of computer networks.

All this is conceived with a protocol logic proposal for the developed synchronization algorithm, and the analysis of interactions from real-time communication sessions which is pointed below with regard to causality and usefulness.

- I've created the synchronization algorithm as a basis for understanding the effects that need to be properly acted upon, in order to tolerate disturbances of the real-time transmission processes. It's purpose is to tolerate intermediate defects that may occur in routed OSI sessions. The algorithm in question works by rerouting data packets through routers that can retrieve and further transmit data packets related to an end-to-end session(between endpoints, sender and receiver);
- As a representation of the problem and to define it's solution, I have also created the necessary method for applying the synchronization algorithm so that it can work properly. The method in itself has the possibilities to analyze the performance autonomously for each routing device, while also activating the synchronization process of the algorithm by reorienting the connections between routers at intermediate levels of networks, subnets, systems and subsystems;

Relevant own publications pertaining to this thesis group: 10 – 24;

4.1.2 Thesis Group 2 (Created Solutions and their Applicability)

I have integrated the concept of interaction in the OSI model to facilitate the logical analysis of effects, actions, reactions and malfunctions that may occur in the cooperation between OSI level 4(transport) and OSI level 5(session) technologies. I've also solved the context of malfunction for real-time transmissions by using the analysis of interactions, and by methodically applying the synchronization algorithm while also assigning the reliability feature to real-time routing of OSI sessions. Pointed out below are the steps that I performed in order to achieve the proposed solutions.

- I've defined a protocol proposal in which the execution steps of the synchronization algorithm can be applied to fulfill the purpose of fault tolerance in real-time communications. It's intended to operate the algorithm, and mainly the algorithmic

actions are performed by a comprehensive performance analysis on the elements that are part of the rerouting process;

- I have created simulation models through which I validate the existence of the real-time communication problem at the OSI session level, representing through them the possibilities for solving the disfunctions from this type of communications;
- I've defined the mathematical formulas that represent the technical possibility of achieving and estimating the limits within which the synchronization algorithm must be framed. Through these, an analysis can be performed in modeling and evaluating the performance characteristics that must be met by the equipment and software that's integrated in the rerouting of data packets from OSI sessions;
- I have established the applicability of the proposed solutions in tolerating failures of real-time data communications through a experimental analysis that's based on real-time transmission performances;

Relevant own publications pertaining to this thesis group: 1 – 9;

For the previously presented thesis groups I performed a concise theoretical documentation on the technological ensemble through which persistent routing is performed. Through these, I assigned the reliable communication characteristic to computer networks that route session-level data. The ensurance that a real-time communication process is part of the reliability framework is given by the analysis of the routing resources through which disruptive effects are mitigated. In this way, the routing process is maintained as functional through the use of some network segments that were chosen in terms of performance.

Markov Chains and Queue Theory were presented in terms of persistent routing. These led to the analysis and representation of persistent routing and the concept of interaction based on event-time states. We mentioned these elements in terms of their usefulness in modeling the performance of real-time transmissions from communications networks. As parameters, they are mainly highlighted by the existing analytical possibilities, while these are in turn given by the observable behavior of data routing by mapping actions as transmission events(Markov Chains) in limited time frames(Queues).

The analysis methodology as a whole is formed by the existing technology from the current state of the art research. Because it's a process(real-time routing) which requires guaranteed performance for the operation of communication media, persistent routing was analyzed through terms of functional analysis. These were described informally, because each method includes measurement and control metrics that underlie the description of the performance of transmission. In this way, I argument the existing units, indices and parameters to present this study's validation method, namely the simulation of data transmissions in an abstract manner, which corresponds to the session level of the OSI model.

Performance evaluation models were created in simulation contexts because they were the only affordable experimentation possibility of this study. Logically, persistent routing is performed in the form of a trajectory that's followed continuously by data packets. These are transmitted through the same segments because each packet arrives at the same router, and data is forwarded to the same destination. From this point of view, having short communication intervals between the serviced packets implied that the routers that are chosen need to be the same, because there is no need for a distance and path vector re-computation for an already initiated real-time session.

Chronologically, I wanted to conduct an extensive study to present the impact of the concept of Interaction and of created synchronization algorithm on fault tolerance for real-time transmitted sessions. I have accomplished this by edifying the applicability of the proposed solutions with the representation of secondary contributions. The significance of these aspects is presented in the following paragraphs together with the explanations related to the current technologies that were improved for persistent routing.

Artificial intelligence search techniques are an abstract methodology for formulating solutions to unrealistically specified problems, but which could present achievable patterns in the real world of data communications. This was a first theoretical contribution that I made because in an ideal world, that's saturated with resources and possibilities to route, various topological schemes could be implemented to maintain in an evenly dispersed manner per nodes of routing, the arrangement of data traffic in routing regions. For the real world context, in which engineering utility is highlighted, artificial intelligence techniques are not used due to the high cost of time to transmit packets from source to the intended recipient.

I presented the topic in question in Articles 24, 23, 22, 21 and 20, as sufficiently explicit in motivating why artificial intelligence is just a holistic approach to computer networks. We conducted a concise documentation on the core technologies that are used in the whole world, and continued to address the flaws found in real-time OSI session transmissions.

In Article 19, we presented the identification of discrepancies between routing technologies that are categorized by the OSI model and related the dependencies between them through the series of events that interact by using synchronized mechanisms. Based on the mapping of interaction in a conceptual form in the analysis of the actions that take place in device sets, we defined the logical methodology for recognizing the central points involved in real-time data routing.

The doctoral study was extended by analyzing performance metrics and related methodologies for managing quality of service(QoS). In articles 18, 17, 16 and 15, we clarified the key technologies for intra system transitions(AS - AS) that form the Internet and the interconnection techniques through which persistent routes operate. At the same time, through these papers I started to present the analysis of interactions between levels 4 transport OSI and 5 session OSI, as well as the discrepancies between the technologies related to real-time transmissions. They were completed experimentally starting with scientific papers 14, 13 and 12, in order to present the types of transmissions that make use of persistent routes together with the way to identify the transmission problem in real time. Also in those articles, a series of experiments were created using simulation tools, and through the prism of time-based performance analysis metrics from queue theory, a methodology on how to approach the problems from OSI sessions was represented.

In article 11 the methods of applying reliability for real-time sessions was represented. From the basic feature of trust on the smooth running of persistent routes, simulation models were created to reflect real contexts of global network dynamics and also to present how to autonomously adjust the parameters that coordinate data packets of OSI sessions. The models in question were presented in papers 10 and 9, with the role of introducing fault tolerance through the proposed synchronization algorithm for persistent routes of sessions that run in real-time. At the same time, these are contributions through which the reliability of attenuating errors/defects on a single transmission route can be achieved.

Through scientific paper 8, there was the goal to define the analysis of transitive logical states that data packets go through, and through this, the definition of parametric options that can be integrated into the real-time transmission protocol was facilitated. These options would have the role of mitigating disruptions and communication errors between network equipment by operating the proposed algorithm, and being at the same time a contribution that would significantly reduce the time costs of routed packet traffic. Also, the contribution I claim shows there is no reason to have additional technical usage, time delay(routing and updating of routing tables) and financial costs, to tolerate defects through duplicate routes of OSI sessions.

In papers 7 and 6, I performed some detailing of the logical method by which the analysis of interactions from persistently routed sessions can be performed. Article 7 was based on the connectivity elements provided through time windows and TCP agreements, through which the synchronization algorithm could be implemented. Article 6 highlighted the ways to find optimal routes through vast routing pools. To be reminded, is that this study focuses on connection oriented routing. Transmissions of this type are created by means of handshake agreements that use the structure of TCP datagrams, as

opposed to connectionless communication which use only UDP datagrams and packets are passed from router to router without any acknowledgment. TCP packets guarantee transmissions or at least provide an error rate on the inability to continue on a route. Given these technological effects, in articles 5 and 4 I have provided further details on how to apply the interaction analysis in fault tolerance for OSI sessions. Article 3, represented a logical summation of the transmissions through a new simulation model. In that model an approach to the problem of persistent routing was performed, in order present the management of logical queues as a complement to software⁴⁵ that's implemented in routing equipment.

The most recent creational article, 2, was a paper dedicated to understanding the creation, concretization and definition of virtual time quanta's that show how the beneficial use of cycled time can provide a more coherent resource usage in the Internet world.

In short, the analysis of interactions was presented in articles 2 – 19, and the synchronization algorithm was presented as utility, creation and applicability in articles 2 - 13. The proposed protocol was presented deductively in articles 2 – 13, and I state deductible because any mechanism, algorithm and logical method of routing is operated through networks by using routing protocols. The logical links between these three main contributions are natural, being supported by the technological reviews from articles 19 - 24 where various routing technologies and programming methods are identified. The last article published till the end of this thesis's edit, article 1, is comprised from a review that presents in a journal, all the creational manuscripts that were published (2 – 19) as part of the proposed scientific solutions and findings, in the form of a cursive read for this study.

All these contributions, which include the decision charts for the proposed improved protocol, the synchronization algorithm and the autonomous analysis of interactions, are solutions that I consider auspicious in the research on computer networks. Some of the published articles have been cited in other doctoral theses, or in scientific papers that are also indexed in international databases such as IEEE, DBLP, ISI Thomson Reuters and Google Scholar. As an additional contribution, I would also like to claim the documentation undertaken in the articles, this being concise and covering a wide range of bibliographic reference elements that have a high degree of novelty and engineering applicability in various fields.

I end this subchapter with the mention that the study was carried out with an experimental methodology composed of conventional X64 hardware, and discrete event simulation software, run on the computing platform with java microcode virtualization. The methodology was good enough to perform realistic experiments, and from an analytical point of view, I created the formulas and relations⁴⁶ that I claim for the synchronization algorithm logic and the concept of interaction formulation.

4.2 Future Research Directions

The study I developed is at a level where the addressed issue, persistent route communication of real-time sessions, can be supported, completed and analyzed on several levels. As an author, I realized that the study I conducted, and the contributions that I claim, can be applied in several technological areas that make use of real-time communications. In addition to real-time transmissions, infrastructure technologies could benefit from performance improvements both at the network level of the OSI model, and at the data and physical link levels of the same organizational model. In the following list, I will briefly describe what are the possible continuations and directions of research that I consider to be complementary ideas to this document.

⁴⁵ The devices in question are designed to be closely related to physical buffers (hardware buffers).

⁴⁶ Relations and formulas claimed au based on reference works in the field.

1) Creating experiments that have the purpose of applying the terms presented in this thesis, but in other simulators that are able to represent discrete events and to analyze network phenomena.

2) To create the algorithmic mechanisms that apply the execution steps of the claimed synchronization algorithm in a communication protocol that reflects the protocol logic that I also designed and described in Chapter III of this document.

3) Designing methods for accessing computing equipment and resources, to find more optimal coding methodologies for real-time transmissions.

4) Defining a hybrid computing architecture for communication equipment that can streamline the volume of data that's communicated in real-time, through composite networks that have structures specially created to serve this purpose.

5) Implementation of the synchronization algorithm on several performance evaluation models, with different computation laws that can present in a special way, the interactions between transport technologies and the criteria for establishing real-time sessions.

6) Formalization of temporal evaluation metrics for data communications that have the dispersion of packets in adjacent environments as an existing facility and possibility. This could give to the reorientation of real-time connections, an increased index to meet the fault tolerance effect, and even a normal value to the core network and infrastructure services.

I conclude this document by saying that this study was a great opportunity for me to improve the field of computer networks, completing a small step in the continuous development that this interesting field offers to people that are passionate about computer networks.

V. PUBLISHED WORK

In this chapter I briefly present the obtained doctoral results. These consist from the publication of a number of 24 articles, work that I have sustained in front of other researchers that were participating at profiled scientific conferences. The articles were all evaluated and published in journals and international databases such as Springer, ISI Thomson Reuters (fig. 5.1), IEEE Xplore (fig. 5.2), DBLP, Google Scholar, etc. .

The screenshot displays a search results page from ISI indexing. At the top, there is a navigation bar with 'Sort by: Date' selected, and options for 'Times Cited', 'Usage Count', 'Relevance', and 'More'. A page indicator shows '1 of 2'. Below the navigation bar, there are utility buttons: 'Select Page', a printer icon, an email icon, '5K', a 'Save to EndNote online' dropdown, and an 'Add to Marked List' button. On the right side, there are links for 'Analyze Results' and 'Create Citation Report'. The main content area lists four publications, each with a checkbox, a title, author information, conference details, and citation statistics. The first publication is 'Performance Queues for Fault Tolerant Sessions' by Orzen, Stefano-Niko; Stratulat, Mircea, with 0 citations. The second is 'Data Packet Header Actions in Fault Tolerance of Persistent Routing Sessions' by Orzen, Stefano-Niko; Babii, Sorin, also with 0 citations. The third is 'Network Events in the Dynamic Selection of Real-Time Session Fault Tolerant Routes' by Orzen, Stefano-Niko; Babii, Sorin, with 0 citations. The fourth is 'Routing Tables as Big Data Searchable Structures for Achieving Real-Time Session Fault Tolerant Rerouting' by Orzen, Stefano-Niko; Stratulat, Mircea; Babii, Sorin; et al., with 1 citation.

Item	Title	Author(s)	Conference	Date	Pages	Published	Times Cited
1.	Performance Queues for Fault Tolerant Sessions	Orzen, Stefano-Niko; Stratulat, Mircea	13th International Symposium on Electronics and Telecommunications (ISETC)	NOV 08-09, 2018	203-206	2018	0
2.	Data Packet Header Actions in Fault Tolerance of Persistent Routing Sessions	Orzen, Stefano-Niko; Babii, Sorin	15th IEEE International Symposium on Intelligent Systems and Informatics (SISY)	SEP 14-16, 2017	193-196	2017	0
3.	Network Events in the Dynamic Selection of Real-Time Session Fault Tolerant Routes	Orzen, Stefano-Niko; Babii, Sorin	21st IEEE International Conference on Intelligent Engineering Systems (INES)	OCT 20-23, 2017	301-304	2017	0
4.	Routing Tables as Big Data Searchable Structures for Achieving Real-Time Session Fault Tolerant Rerouting	Orzen, Stefano-Niko; Stratulat, Mircea; Babii, Sorin; et al.	17th IEEE International Symposium on Computational Intelligence and Informatics (CINTI)	NOV 17-19, 2016	261-264	2016	1

Figure 5.1 ISI Indexing example

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Interaction understanding in the OSI model functionality of networks with case studies

Stefano-Niko **Orzen**
2014 IEEE 9th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI)

Year: 2014

Pages: 327 - 330

IEEE Conferences

[▶ Abstract](#) [\(\(html\)\)](#) (635 Kb)

Network events in the dynamic selection of real-time session fault tolerant routes

Stefano-Niko **Orzen** ; Sorin Babii

2017 IEEE 21st International Conference on Intelligent Engineering Systems (INES)

Year: 2017

Pages: 000301 - 000304

IEEE Conferences

[▶ Abstract](#) [\(\(html\)\)](#) (3883 Kb)

Figure 5.2 IEEE Explore indexing example

I would also like to mention that the articles in the following list have been cited until the date of writing this thesis in the works of about 10 researchers (fig. 5.3), these being also internationally indexed articles or doctoral thesis's. Own citations are excluded from the number of mentioned authors, this being observable by filtering the search results from websites like IEEE Explore Digital Library, Google Scholar and Thomson Reuters ISI Web of Science.

- 1) S.N. Orzen, L. Kovacs, Internet Time as Virtual Time for Real-Time Session Routing, INES 2020, IEEE indexed;
- 2) S.N. Orzen, M. Stratulat, Performance Queues for Fault Tolerant Sessions, ISETC 2018, IEEE indexed;
- 3) S.N. Orzen, S. Babii, Network events in the dynamic selection of real-time session fault tolerant routes, INES 2017, indexed IEEE and Google Scholar;
- 4) S.N. Orzen, S. Babii, Data packet header actions in fault tolerance of persistent routing sessions, SISY 2017, indexed IEEE and Google Scholar;

- 5) S.N. Orzen, M. Stratulat, S. Babii, C. Cosovan, Routing tables as big data searchable structures for achieving real-time session fault tolerant rerouting, CINTI 2016, indexed by ISI Thomson Reuters, IEEE and Google Scholar;
- 6) S.N. Orzen, M. Stratulat, S. Babii, C. Cosovan, Connectivity for routing persistent connections, ISETC 2016, indexed by ISI Thomson Reuters, IEEE and Google Scholar;
- 7) S.N. Orzen, M. Stratulat, S. Babii, C. Cosovan, Markov Chains state transitions for reliable persistent routing, INES 2016, indexed by ISI Thomson Reuters, IEEE and Google Scholar;
- 8) S.N. Orzen, M. Stratulat, S. Babii, C. Cosovan, Fault tolerance of propagated errors in persistent real-time routing processes with a synchronization based algorithmic method, SACI 2015, Timisoara, Romania, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 9) S.N. Orzen, Performance metrics for persistent routing, SOFA Workshop 2014, Timisoara, Romania, inclusion in Springer Journal of Advances in Intelligent and Soft Computing, indexed by ISI Thomson Reuters, IEEE, Springer Journal, Scopus and Google Scholar;
- 10) S.N. Orzen, S. Babii, Time resolution for defining an optimal path with neural networks and graph structuring, SISY 2014, Subotica, Serbia, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 11) S.N. Orzen, S. Babii, User-centered end to end optimal persistent routing, CogInfoCom 2014, Vietri sul Mare, Italy, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 12) S.N. Orzen, Network protocol design for persistent performance routing, ISETC 2014, Timisoara, Romania, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 13) S.N. Orzen, Interaction understanding in the OSI model functionality of networks with case studies, SACI 2014, Timisoara, Romania, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 14) S.N. Orzen, Domain relations in trees arborescence for interaction search on persistent routing availability, SAMI 2014, Herl'any, Slovakia, indexed by ISI Thomson Reuters, IEEE, Scopus and Google Scholar;
- 15) S.N. Orzen, Mathematical expressiveness for computational network interaction, SACI 2013, Timisoara, Romania, indexed by ISI Thomson Reuters, IEEE, DBLP, Scopus and Google Scholar;
- 16) S.N. Orzen, Performance design and criterion analysis for efficient data routing, Scientific Bulletin of "Politehnica" University of Timisoara, Transactions on Automatic Control and Computer Science, Series AC, no.1, 2014, indexed Google Scholar;
- 17) S.N. Orzen, Requirements for time based graph structuring with specialized and generalized path choice routing, Scientific Bulletin of "Politehnica" University of Timisoara, Transactions on Automatic Control and Computer Science, Series AC, no.2, 2013, indexed Google Scholar;
- 18) S.N. Orzen, The concept of interaction resolutionally applied in distributional computer networks connectivity, INCER 2013, Bucharest, Romania;
- 19) S.N. Orzen, Distributed systems and artificial intelligence in programming (Proof of Concept), Development and Application Systems, Suceava, Romania, 2012, indexed Google Scholar;
- 20) S.N. Orzen, Computational processes in distributed systems administration and engineering, POSDRU Workshop no.3, Pitești, Romania, 2013;
- 21) S.N. Orzen, The design of programmability in information technology, POSDRU Workshop, no.2, Oradea, 2012;
- 22) S.N. Orzen, Ș. Holban, Data representation for communication networks - information integration and programmability, Scientific Bulletin of "Politehnica" University of Timisoara, Transactions on Automatic Control and Computer Science, Series AC, no.1, 2013, indexed Google Scholar;
- 23) S. Holban, S.N. Orzen, Artificial intelligence in distributed systems programming, POSDRU Workshop no.1, Timisoara, Romania, 2011;

Markov chains state transitions for reliable persistent routing

[SN Orzen, M Stratulat, S Babii...](#) - 2016 IEEE 20th Jubilee ..., 2016 - [ieeexplore.ieee.org](#)

The work presented in this article analyzes the Markov chain transition process for achieving reliable persistent routes. State representations of data packet traversals through networks, signify events that can be measured, tuned and optimized, in order to provide a reliability ...

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Interaction understanding in the OSI model functionality of networks with case studies

[PDF] [ieee.org](#)

[SN Orzen](#) - 2014 IEEE 9th IEEE International Symposium on ..., 2014 - [ieeexplore.ieee.org](#)

The work presented throughout this paper deals with the continuous research on the OSI model's applicability to convey a certain functionality in computer networks. Computer networks represent mathematical formalisms and algorithmic organization which as ...

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Network events in the dynamic selection of real-time session fault tolerant routes

[PDF] [ieee.org](#)

[SN Orzen, S Babii](#) - 2017 IEEE 21st International Conference ..., 2017 - [ieeexplore.ieee.org](#)

In this paper the creation of network events and their usefulness is presented for real-time session fault tolerance. Network fault tolerance is a defined event driven action and for real-time sessions the timely processing of events is of the highest importance. Real-time ...

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In this paper the networked routers decision support tables are presented as big data structures. Routing tables ease the modeling of interconnected networks traffic and update costs, and have grown in size presenting a multitude of possibilities for communication ...

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Internet Time as Virtual Time for Real-Time Session Routing

[PDF] [ieee.org](#)

[SN Orzen, L Kovacs](#) - 2020 IEEE 24th International Conference ..., 2020 - [ieeexplore.ieee.org](#)

This paper is a continuation of the research done for providing reliability to real-time session routing. As such, we focus on the internet time measurements and the constituent parts that form virtual time as a measurement indicative which is useful for managing resources. The ...

☆ ⓘ

Performance Queues for Fault Tolerant Sessions

[PDF] [ieee.org](#)

[SN Orzen, M Stratulat](#) - 2018 International Symposium on ..., 2018 - [ieeexplore.ieee.org](#)

This paper presents the usefulness of queues in providing fault tolerance for real-time transmissions. Network environments gain more and more hosts every minute and because of this issue the productivity and dependability of interconnected environments have ...

☆ ⓘ Related articles

Fault tolerance of propagated errors in persistent real-time routing processes with a synchronization based algorithmic method

[SN Orzen, M Stratulat, S Babii...](#) - 2015 IEEE 10th Jubilee ..., 2015 - [ieeexplore.ieee.org](#)

This paper presents a focus on the error propagation aspect which exists in interconnected networks. For handling the issues and considerations implied by this negative property, a method for ensuring fault tolerance and reliability of real-time routing processes is ...

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Network protocol design for persistent performance routing

[PDF] [ieee.org](#)

[SN Orzen](#) - 2014 11th International Symposium on Electronics ..., 2014 - [ieeexplore.ieee.org](#)

This paper presents the design methodology and abstraction of network elements for creating reliable persistent routes. Persistent routing is introduced in section one with it's problem definition through network elements and their respective functions, having section ...

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Connectivity for routing persistent connections

[PDF] [ieee.org](#)

[SN Orzen, M Stratulat, S Babii...](#) - 2016 12th IEEE ..., 2016 - [ieeexplore.ieee.org](#)

This paper is focused on the connectivity feature for routing persistent connections. Real-time session communications are presented with their elements and performances, the requirements to generate and maintain connections as being active, as long as these are ...

☆ ⓘ Cited by 1 Related articles

Figure 5.3 Example of cited work

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