NB-IoT Technology and its Application

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Abstract— **In June of 2016 the 3rd Generation Partnership Project (3GPP) completed the standardization of Narrow Band IoT (NB-IoT). NB-IoT is a Low Power Wide Area Network (LPWAN) radio technology for the Internet of Things using conventional cellular network. It focuses on increased coverage, lower costs, extended battery life and enabling a vast number of connected devices. Using unexploited LTE resources, narrow band technology does not require new infrastructure to be built. In this article, a universal NB-IoT device and software framework was designed. It can be equipped with several types of sensors – along with its platform. The final tests of the device can be performed according to the deployment of base stations.**

I. Introduction

The fourth industrial revolution (Fig. 1) not only brings digitalization, robotization and automation, but establishes a different business paradigm which, with all its innovations raises up a new concept, called Industry 4.0 for short.

This revolution is still ongoing, more and more cyber-physical system appear that means informatics, mechanics and software are tightly coupled. Cyber-physical systems are realized by interconnections of embedded devices by means of wired, or more preferably by wireless technology. Problem arises when devices had to be connected to a network that is hardly accessible, or there is no way to use conventional methods to do so, or financially not viable.

These problems were addressed by 3rd Generation Partnership Project (3GPP) in June of 2016. In its Release 13 a new technology, called Narrow Band IoT, was introduced.

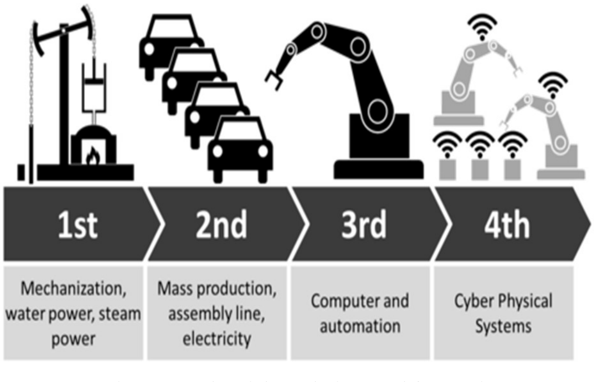

Figure 1. Industrial revolutions and future view

Narrow Band is a Low Power Wide Area (LPWA) standard radio technology, specifically designed for the Internet of Things. It focuses on improved coverage, reduced costs and prolonged lifetime (Fig. 2).

According to Telekom's analysis, approximately 3 billion LPWA devices are to be connected around the globe by 2023 [1].

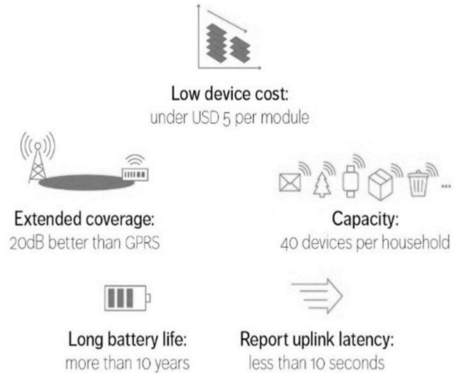

Figure 2. Benefits of NB-IoT [2]

That is why we are motivated to design a full NB-IoT solution, because currently there is no general solution yet.

II. Technical Overview

A. Low Power Wide Area

LPWA networks give reasonable range with minimal power consumption. According to Machina's research this will be the fastest growing IoT technology [3].

These networks have two main aspects:

1. Low Power

Devices designed for LPWA networks are optimized in hardware and software as well, thus able to function for many years powered from a single battery. Power consumption is so low, it is comparable to the self-discharge of the battery, making it unnecessary to replace the power source ever. Therefore, these devices can be placed in hard-to-reach environments.

2. Wide Area

Technological advances make it possible to have increased transmission power and receiver sensitivity, obstacles and interference are easier to cope with.

Conventional networks, like Bluetooth, Wi-Fi or ZigBee, along with classical cellular technologies, are not efficient enough, requires considerable amount of investment and power consumption is a concern as well.

On the other hand, LPWA devices are relatively cheap, uses existing infrastructure and require minimal, or no maintenance.

B. Narrow Band IoT

Table 1. Technical parameters

Frequency band	NB-IoT (LTE) FDD bands 1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 25, 26, 28, 66, 70
Mode	Half-duplex FDD type B
MIMO	not supported
Bandwidth	180 kHz
Multiple Access	Downlink: OFDMA Uplink: SC-FDMA
Modulation	Downlink: QPSK Uplink: Single Tone: π/4-QPSK, π/2-BPSK Multi Tone: QPSK
Coverage	164 dB (+20 dB GPRS)
Data rate	~25kbps downlink and ~64 kbps uplink
Propagation	<10 seconds
Power savings	eDRX, Power Saving Mode

1. Channel scanning and connection establishment

The key feature of an NB-IoT device is the ability to adapt to changes in the environment. This property is defined in Physical Random Access Channel (PRACH) requirement which ensures sufficient link quality to cells [4].

According to 3GPP Release 13, a device, during its power-up, is scanning for available channels and tries to connect to them using one of the three signals [5]:

1. Narrowband Cell Reference Signal (NRS)
2. Narrowband Primary Synchronization Signal (NPSS)
3. Narrowband Secondary Synchronization Signal (NSSS)

NRS signal is used by the User Equipment (UE) to determine the performance of the downlink and is present in every downlink subframe.

NPSS and NSSS estimates (Fig. 3) time and frequency properties with a primary signal in every 5th subframe and a secondary signal in every 9th subframe of frames with even numbers.

With these properties at hand, the device is ready to receive Narrowband Physical Broadcast Channel (NPBCH) signal, in which, it acquires Master Information Block (MIB-NB). The MIB-NB informs the UE, in what modes the cell is operating [6]:

a) Stand-alone (reused GSM frequency band)
b) In-band (inside the LTE spectrum)
c) Guard-band (next to an LTE Physical Resource Block - PRB)

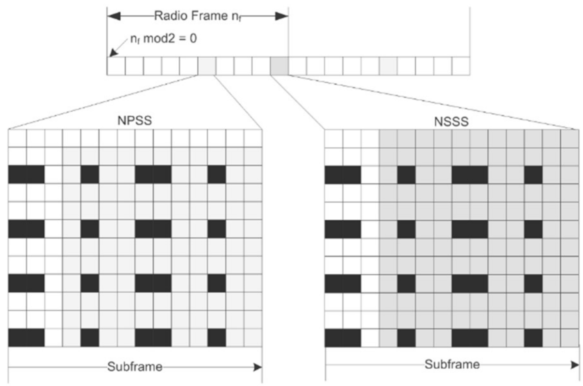

Figure 3. Primary and secondary synchronization signals [7]

Every NB-IoT device should support all modes and configure itself based on the information provided.

Narrow Band technology does not require as much resource as standard LTE or GSM, as datarate is lower, handover is not implemented and there is no support for Multiple-Input and Multiple-Output (MIMO) [8].

2. Energy Saving Methods

But the lifetime of an NB-IoT device is still heavily dependent on the power source it uses, therefore it is critical to optimize power consumption. Optimizations can be done at hardware level, but a thoroughly designed software is the essence.

3GPP Release 12 defines the Power Saving Mode (PSM), which enables a device to sleep indefinitely. In this state, the UE is unreachable but can be woken up by its internal components, or when the Tracking Area Update (TAU) times out (Fig. 4).

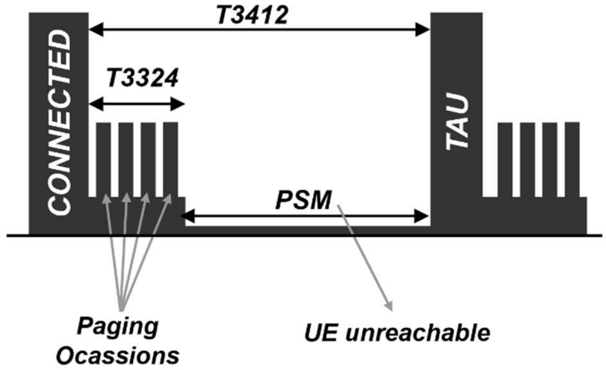

Figure 4. Release 12 Power Saving Mode [9]

3GPP Release 13 defines another power saving technique, the Extended Discontinuous Reception (eDRX), in which the UE can sleep for longer time before it checks back into the network (Fig. 5-6). The UE tells the network how many units of time it would like to sleep and during that time, traffic is queued.

eDRX is useful for applications when frequent downlink is expected.

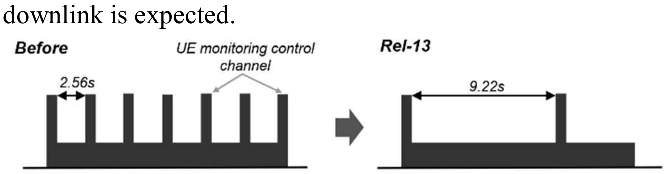

Figure 5. Rel-13 eDRX connected [9]

Figure 6. Rel-13 eDRX idle [9]

III. DESIGN

A. Specification and objectives

During design phase, the main motivation was to develop an NB-IoT device, which lets future adaptation and takes the integration realized easier.

To achieve this goal, we designed a hardware which not only complies with the IoT norms (minimal power consumption and size), but it can be used in many applications by providing sufficient interface for external components, like sensors and control elements.

B. Hardware

The hardware components were chosen to meet the requirements of technological trends to the greatest extent possible. Key considerations are functionality, power consumption and size. The device consists of the following main elements (Fig. 7):

1. NB-IoT enabled module
2. microcontroller
3. power source
4. peripherals and extensions

Nowadays Quectel and U-Blox has working solution for NB-IoT. Both modules are based on Huawei's chipset, but only the Quectel BC95 is available in our region [10].

Because the BC95 module has no dedicated user-application processor, we had to use an individual one in order to control the module, sensors and manage resources. We selected a modern, yet ultralow consumption type one from the range of STMicroelectronics ARM Cortex-M architecture processors. The STM32L041G4 was chosen due to its processing power, low-power modes, peripherals and package [11].

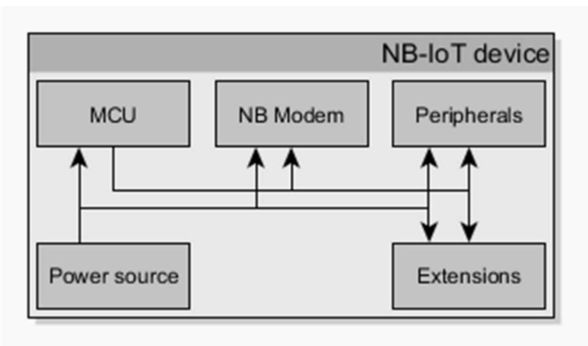

Figure 7. Architecture of the device

The built-in Real Time Clock (RTC) module can keep track of time while the whole device is in sleep mode.

As a matter of constant concern for our world, IT security, encrypted data can be easily generated by its AES-128 crypto-module.

Power is provided by a standard Li-Ion battery, whose capacity will be chosen based on preliminary power consumption and required lifetime.

Regarding the status of the microcontroller and the modem, two major and several minor states were distinguished in the calculations:

1. Active state
   a. data acquisition, measurements
   b. processing
   c. transmission
2. Inactive state

In the active state, the microcontroller gathers data from the environment by reading sensors, process the acquired data and transmits them through the NB-IoT module. After completion, the whole device enters the inactive state.

While the device is inactive, power consumption is at minimum, microcontroller is stopped and the NB-IoT module is in PSM or eDRX. If any event happens, the device enters into the active state again and performs actions.

Time spent in the states and the actions performed are periodic and almost equal in power consumption, therefore lifetime can be calculated based on the individual power consumption of different processes. Calculations are based on electrical charge as a resource:

$$Q = \int I(t)dt = I_{avg} * \Delta t \quad (1)$$

Consumption of different states and actions can be summed up to get the amount of charge used in a period of time. Then, the sum of these charges and the time of the period gives the average consumption.

$$Q_i = I_i * t_i \quad (2)$$

$$Q = \sum_{i=0}^{n} Q_i = \sum_{i=0}^{n} I_i * t_i \quad (3)$$

$$I_{avg} = \frac{Q}{\Delta t} \quad (4)$$

Battery capacity can be calculated from the average current extended to the required lifetime and estimated efficiency:

$$Q_{bat} = I_{avg} * t_{lifetime} * \frac{1}{\eta} \quad (5)$$

For example, if a device has an average power consumption of 100mA for 10 seconds, then 10uA for the rest of the day, battery capacity for a 10 years lifetime with 75% efficiency would become:

$$Q_0 = 100mA * 10s = 1As \quad (6)$$

$$Q_1 = 10uA * 86390s = 0.8639As \quad (7)$$

$$I_{avg} = \frac{Q_0 + Q_1}{1\,day} = \frac{1As + 0.8639As}{86390s} = 21.58uA \quad (8)$$

$$Q_{bat} = 21.58uA * 10\,years * 75\% = 2520mAh \quad (9)$$

, which is not too large considering 10 years of operation. Of course, most of the applications require more active time than 10 seconds a day, but it can be admitted, it is possible to operate a device for many years from a single battery cell.

C. *Platform*

To make a robust solution and to facilitate future development, we decided to create a complex system, which we call platform, to give an abstraction to the hardware, software and web service as a whole. With this abstraction, new applications can be implemented without spending time on development.

Aside from minimizing the size of the design, we added extension connectors to support connection for common serial interface components, most commonly using I2C, SPI or UART. We dedicated these peripheral signals as well as some general I/O lines for control purposes.

For simplifying development of the device, a concept of a complete firmware library was created, in which all the functionality would be implemented and hidden from the programmer in the form of an API. This library would act like an operating system and would guarantee minimal power levels and robustness by design. The API would reduce application logic to a few function calls. Furthermore, a graphical programming language could be developed for this purpose. The library could handle Firmware Over-The-Air (FOTA) and implements failsafe mechanisms.

Data are transmitted to the web in the popular JSON format, which enables flexible useage, different types of data can be enclosed in a single message and almost every web service could handle JSON format.

Transmitted messages always contain unique identifiers, battery voltage level, network statistics and auxiliary flags, so a fleet management solution can be easily built to constantly monitor deployed devices, giving notifications on different events.

IV. CONCLUSION

NB-IoT has a great potential for the world today. By using the LTE network, it is cheap to implement by operators and can emerge rapidly. It provides good coverage and with proper design, can last for 10 years or for more.

With our design, many applications can be implemented by attaching a little extension board to the device and thanks to the platform, it requires minimal configuration to operate.

According to previsions, vast number of NB-IoT devices will be connected to the internet, which means, Big Data solutions or Artificial Intelligence should be implemented later to handle and process huge amount of data.

Some of the applications are focusing on smart devices used in cities and facilities:

A. *Smart City*

There is no better use of NB-IoT technology, where long-life and maintenance-free solutions are most critical. Smart city is an idea to manage urban assets based on IoT solutions.

B. *Smart lighting*

A city with many street lamps consumes a considerable amount of power. By replacing them to more efficient LED lights and remotely controlling them individually, lamps could be lit where it is needed, thus minimizing utility costs.

C. *Smart parking*

It is always a challenge to find parking place in a crowded parking lot. It takes time, fuel and is stressful. If every parking place had a sensor to indicate vacancy and provides connection to the internet with NB-IoT, vehicle owners could get notified about available spots nearby, or they could search them manually on their phone.

D. *Smart Bin*

Cities have their schedules for waste collection. This means excessive waste is not removed before the next schedule or there is no need to remove at all. Therefore, managing waste is not as efficient as it could be. Using NB-IoT, waste collection could be scheduled on demand, saving time and fuel.

The device and its platform significantly accelerates the development of further solutions. Now in Hungary, and surrounding countries had no available NB-IoT network, we could not manage the final tests of our design yet.

Based on provisions and preliminary calculations, carefully designed NB-IoT devices testify properties stated in 3GPP standards. Narrow Band IoT devices can be run maintenance-free throughout their lifetime due to their low power consumption.

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