NARROWBAND INTERNET OF THINGS: PROTOTYPE DESIGN AND HANDS-ON EXPERIENCES

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Abstract: With the IoT (Internet of Things) and upcoming next-generation communication systems, demand for low-power devices keeps growing on the worldwide scale. This paper presents a design of a universal device prototype for LPWAN (Low-Power Wide Area Network) technology called NB-IoT (Narrow Band Internet of Things), the latest member of the 3GPP family standardized in Release 13. Prototype board and its components are introduced alongside with the application that controls all the elements and the communication. In the end, initial measurements of power consumption, transmission reliability and delay are shown and evaluated.

Keywords: LPWAN, NB-IoT, PSM, Industry 4.0, IoT

1 INTRODUCTION

LPWAN technologies become more and more popular with the currently hot topic of IoT. The number of low-power devices connected to the Internet for purposes of sensing, smart metering, and others is rapidly growing. Most widely used representatives of LPWAN technologies are (i) LoRa, (ii) SigFox and now they have been joined by (iii) NB-IoT [1]. What is common for all of them is the low transmission speed and narrow bandwidth. The biggest difference between them is the frequency spectrum they use for the communication. First two technologies fall into unlicensed spectrum category which can be shared with other technologies, whereas NB-IoT gains the advantage from the licensed spectrum [2]. There are obvious drawbacks of the shared spectrum, and that is interference with other devices [3].

2 DEVELOPED NB-IOT PROTOTYPE

The authors decided to evaluate NB-IoT technology as its novelty has brought many challenges. At the time when the research has begun the NB-IoT infrastructure was far from release state. Moreover, the availability of NB-IoT modules was strictly limited to the vendor's partners. At this point, the cooperation with telco operator Vodafone had been established, which provided researchers with first modules and the access to network infrastructure. Following the above, in the sections below, the particular steps of the prototype design are elaborated in more details.

2.1 NB-IoT SPECIFICATIONS

NB-IoT specifications were standardized in LTE (Long Term Evolution) Release 13 as complementary LPWAN service of cellular oriented networks in licensed bands. The aim of the 3GPP was to come up with technology which fulfills MTC (Machine Type Communication) demands: (i) long battery life, (ii) enhanced coverage, (iii) the coexistence of a large number of devices, (iv) low complexity, and (v) price. The NB-IoT meets all these specifications and provides battery life longer than 10 years, and extended coverage with maximum coupling loss up to 164 dB, which is 20 dB more than GPRS (General Packet Radio Service) can provide. The NB-IoT is possible to deploy in three different ways in the LTE carrier (in-band), in the guard band (guard-band) or as an independent band (standalone). Our research partner operates its NB-IoT network in guard band at 800 MHz with different frequencies for uplink and downlink. To reduce costs of the NB-IoT deployment the principles of modulation, coding schemes, and higher-layer protocols are taken from LTE and reused in a new way, which allows coexistence of these technologies at one time. The main difference between NB-IoT and LTE is that NB-IoT introduces 3.75 kHz subcarrier spacing whereas LTE supports only 15 kHz spacing.

The complexity of the NB-IoT devices was reduced by using only 200 kHz band for both uplink and downlink. The constructed device works only in half-duplex mode with frequency division duplex requiring only one antenna. Long battery life is achieved by technologies eDRX (Extended Discontinuous Reception) which allows the device to remain inactive for long period of time and PSM (Power Saving Mode) that completely turn off the radio module for a specific time in accordance with 3GPP TS 24.008 GPRS timer 2 and 3 respectively [3], [4].

2.2 PROTOTYPE BOARD

The developed prototype board is based on the NB-IoT module designated as SARA-N210[1] manufactured by company uBlox. This module is controlled by AT commands transferred via serial line (RS-232). The generator of the serial communication is a microcontroller STM32F103CBT6[2] which is used for controlling the rest of the components placed on the prototype board.

To comply with IoT requirements, powering the board by a LiPol battery was enabled through a power charging IC (Integrated Circuit) MAX8903[3]. The IC is able to charge the battery and power the circuit at the same time. The power is delivered via micro USB (Universal Serial Bus) connector. When the USB is unplugged, the circuitry is automatically powered from the battery.

Very important part of the development board is an on-board GPS (Global Positioning System) receiver Quectel L86-M33[4] with integrated antenna. It was placed there for special use cases where one of them was cargo tracking. The GPS in comparison with NB-IoT is more power consuming so that a power MOSFET (Metal Oxide Semiconductor Field Effect Transistor) was placed on board for the purpose of switching on and off the power to the GPS.

MCU (Microcontroller Unit) is capable of operating various types of sensors due to its hardware capabilities. It can communicate via serial port, I2C, and SPI (Serial Peripheral Interface). Most of the currently available sensors use these communication interfaces and can be tested on our development board in role of data generators.

2.3 SOFTWARE CONTROLLERS

NB-IoT module is, as detailed above, controlled via standard AT commands. Still, the whole instruction chain contains a variety of commands that are not easy to remember and requires execution in exact order. Therefore, the whole process of network registration is automatized, and all data is logged into the console or text file. As it is depicted in Figure 1, the process is divided into three phases. First, the device attempts to register into the network. Going further, in the second step, the UDP (User Datagram Protocol) socket is open. And finally, in the third section, the messages are received or sent. The last step is repeated with the time period specified in command parameters until the application is terminated.

[1] See "SARA-N2 series", 2018: `https://www.u-blox.com/en/product/sara-n2-series`
[2] See "STM32F103CBT6", 2018: `http://www.st.com/en/microcontrollers/stm32f103cb.html`
[3] See "MAX8903", 2018: `https://datasheets.maximintegrated.com/en/ds/MAX8903A.pdf`
[4] See "Quectel L86", 2018: `https://bit.ly/2GEQsYE`

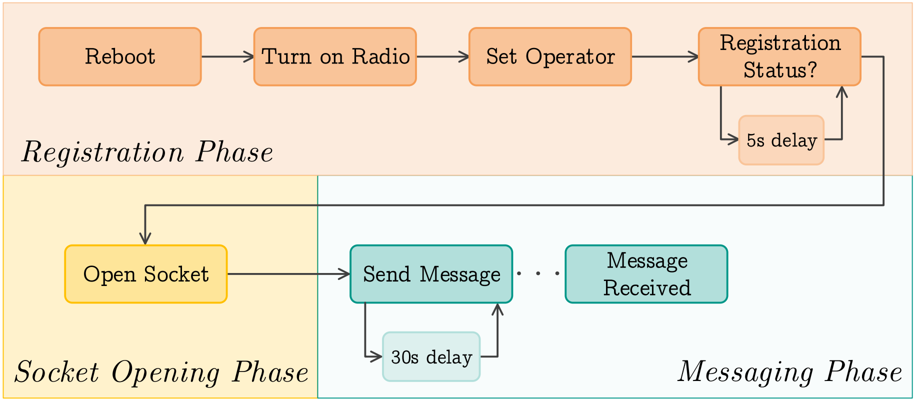

Figure 1: Software controller block diagram.

3 PROTOTYPE EVALUATION

LPWAN communication units are usually considered as battery-powered sensing devices with expected lifespan in orders of years. Therefore authors took into account this premise and focused on the measurements of NB-IoT module's power consumption, reliability, and transmission delay.

3.1 Measurement methodology

Measurements of the current consumption were conducted on Agilent N6705A DC power analyzer with measurement resolution of 1 μA and sampling period of 0.08 ms. This value is a tradeoff between sufficient sampling frequency and required recording time due to the limited internal memory of analyzer. Measurements took 120 s for all the different operating modes of the NB-IoT module to be displayed, see Figure 2.

Transmission delay was calculated from time stamp taken at the beginning of the transmission. This time was subtracted from the time the message was received on the server side. For the transmission delay to be precisely calculated, the time stamps on both ends were synchronized with NTP (Network Time Protocol) using *tik.cesnet.cz* server. Format of the used time stamps was the UNIX time in milliseconds (calculated from 1.1.1970) to facilitate the mathematical operations on the values.

3.2 Power consumption

For battery powered devices power consumption represents the most important parameter. Since NB-IoT is a cellular technology, the differences in consumption should vary during each phase, i.e., network registration, paging, and PSM. Usually, power consumption is considered a product of electric current and voltage in watts. However, if the device is equipped with voltage regulator, as in this case, the voltage is constant, and the only fluctuating variable is electric current. Therefore in this paper, the power consumption is considered as the electric current flowing through the device.

The power consumption profile could be divided into five phases as depicted in Figure 2. In the first phase, the module is attempting to register into the network. The current consumption in this phase is high (about 270 mA) because of data transmission to the network. In the second phase, access to the network is granted, and the device may receive messages. Also, the consumption dropped to 80 mA. In phase three, the message to the remote server is sent, consumption is similar to phase one. The utilized module supports only UDP thus successful transmission is not guaranteed. Fourth phase represents the cyclic paging reception where message reception is still possible. The duration of this phase is determined by GPRS Timer 2 (T3324) [4] and can be changed via AT command – during the measurements it was set to 60 seconds. When the timer expires, the power saving mode

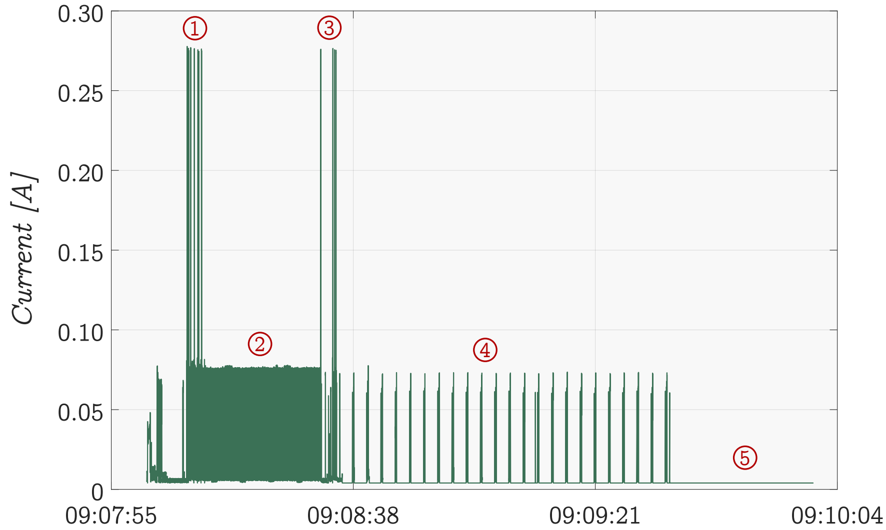

Figure 2: Power consumption of NB-IoT module in different modes: ① Network registration ② Network grant ③ Message transmission ④ Paging reception ⑤ Power saving mode.

is activated. It is expected that device will spend most of the time in this mode because of the low power consumption which does not exceed 4 μA. It is needed to say that in this mode device does not communicate with the network at all and message reception is not possible. Once the device receives a command via the serial link, it switches back to the active mode. Otherwise stays in PSM until the GPRS Timer 3 (T3412) [4] expires.

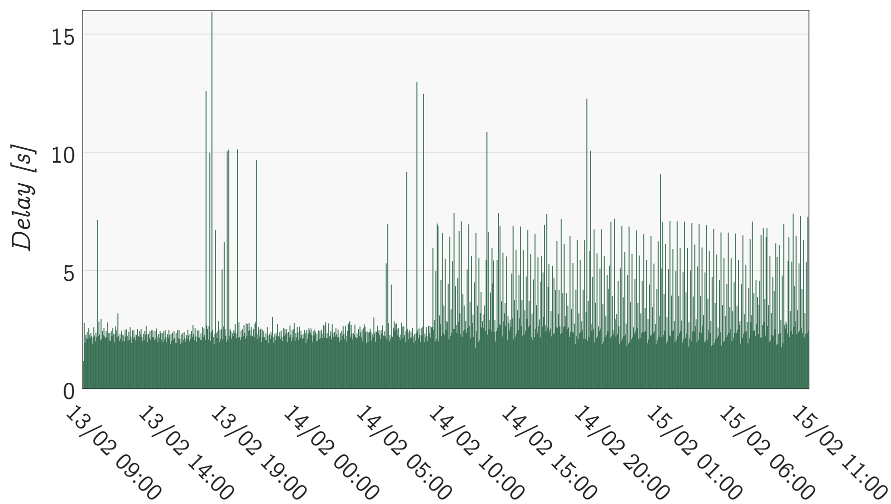

Figure 3: NB-IoT transmission delay in uplink.

3.3 Transmission reliability and delay

The transmission reliability is one of the key parameters in case of smart sensing devices. However, it is strongly dependent on radio channel conditions which may vary through the time. Therefore, long-term measurements of transmission reliability and delay were conducted during 53 hours with message period of 3 minutes and size 450 B[5]. Measurements took place in an indoor office environment at a distance between NB-IoT module and base station not exceeding 500 meters with average

[5]The common size of the message is significantly smaller, i.e., 12 B in maximum in case of Sigfox.

signal strength -60 dBm and SNR (Signal to Noise Ratio) 17 dB. Uplink reliability reached 100% when all 1066 messages were successfully received on the server. Downlink channel indicates some losses, while only 976 messages were received. Nevertheless, it is still 91.7% success rate.

Besides the reliability, the uplink transmission delay was evaluated. As it is depicted in Figure 3, the average transmission delay did not exceed 3 seconds until the middle of measurements. After that, the delay values varied significantly through the time. This deviation could be due to worse radio conditions. Even the message size could play a significant role in this case. Maximum TBS (Transport Block Size) in uplink is 1000 bits therefore 450 B message have to be split into at least four blocks. The NB-IoT module has to transmit this block one by one via radio channel with random access. The system, however, allows only limited number of attempts in the case of failure. If just one block is not sent, the whole message is lost. However, this presumption was rebutted by following measurements. The reliability in downlink did not increase even with smaller messages 20 B and 200 B respectively. At this point, only the mistake in operators infrastructure or modules firmware comes into consideration. As the cooperation with telco operator continues, the authors are entrusted to analyze aforementioned problems.

4 CONCLUSION

In this paper, NB-IoT prototype evaluation was detailed. Authors verified the theoretical parameters of SARA-N210 NB-IoT module; particularly it means its reliability and power consumption. From the perspective of power consumption, the module fulfills all parameters given by datasheet, i.e., 4 μA in PSM, 6 mA in active mode, 280 mA during transmission and 70 mA in reception mode. With only a few messages per day, the 10 years battery life is plausible. The reliability of transmission is at a very high level – in uplink, the transmission is 100 % reliable. In the downlink, the values are lower, but overall reliability is still almost 92 %. Slight disappointment comes with transmission jitter. The transmission delay should not overcome 10 s. However, during the measurements, the delay raised up to 17 s. In spite of this flaw, NB-IoT is promising technology. Based on author's knowledge of NB-IoT roadmap, it will become a key player among the others LPWAN technologies in the close future.

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