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Mobile IoT Systems in the Urban Area

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***Abstract*—An important element of Internet of Things systems (IoT) is wireless data transmission. Narrowband Internet of Things (NB-IoT) and LTE Cat M1 (LTE-M) are the new standards for such transmission intended for LTE cellular networks. Cellular network operators has recently launched such transmission. The article presents the results of measurements of NB-IoT transmission parameters in this network, inside the building and in open urban areas. The main features of the NB-IoT system and measuring equipment are briefly discussed.**

***Keywords*—telecommunications, NB-IoT, LTE, LTE-M, NRSRP, NRSSI, coverage enhancement (CE)**

I. Introduction

THE Internet of Things (IoT) is developing rapidly, new projects and applications are emerging in almost all areas. An important element of IoT is data transmission, especially wireless transmission. First, transmission standards operating in unlicensed ISM bands were created, such as LoRaWan [1] and Sigfox [2]. Shortly afterwards, in 2016, 3GPP published new transmission standards (E-UTRA, version 13) operating in the bands of licensed mobile systems [3], [4]. These systems: narrowband Internet of Things NB-IoT and LTE Cat M1 can work in any 4G system because they ensure compliance with existing cellular standards. It only needs a small portion of the spectrum of the cellular system.

The main features of the NB-IoT system are: increased coverage (Enhanced Coverage) compared to the broadband LTE system, i.e. transmission at 20 dB weaker signal, simplified design of the user equipment (UE), ensuring low cost and long life of the battery (from 10 to 15 years) [5]. These goals were achieved thanks to the possible repetition of transmission in up and down channels, possible single tone transmission, half duplex transmission, simple modulations (BPSK and QPSK) and extensive power saving mechanisms.

NB-IoT standard is designed to support a very large number of devices (52547 in the cell) transmitting small amounts of data at a low intensity. The transmission time of data packets can be significantly extended. Expanded coverage allows for indoor reception, e.g. in basements.

The standard also has disadvantages; the most important are: one antenna (receiving path) and possible significant delays in data transmission.

The paper presents the main features of cellular IoT systems and test results of NB-IoT transmission, recently launched in one of the mobile network, in the 800MHz band. The NB-IoT transmission works in LTE protection band.

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II. Features of IoT Mobile Systems

A. *NB-IoT system*

1) *Basics*

The 800MHz, 900MHz and 1800MHz frequency ranges have been allocated in Europe for the NB-IoT system. They are located in the LTE and GSM system bands. NB-IoT transmission requires a 180 kHz bandwidth, which corresponds to one GSM channel or one LTE block (PRB - Physical Resource Block) [5]. Three types of NB-IoT work are envisaged. This is illustrated in Fig. 1.

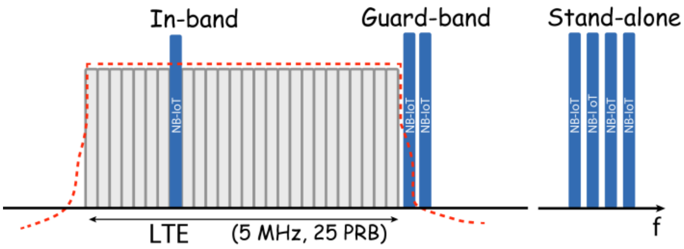

Fig. 1. Types of NB-IoT transmission

Work **in-band**. In this solution, the transmission takes up one PRB block, 180 kHz on the LTE carrier.

Guard band operation when the emission occupies an unused block between LTE carriers.

Stand-alone: NB-IoT occupies one 200 kHz channel in the GSM band. The transmission can take place together with GSM or independently.

Downlink transmission is similar to LTE. OFDM transmission with 15 kHz subcarrier spacing is used. Only 12 subcarriers are used, giving a 180 kHz bandwidth. QPSK modulation was used for subcarrier modulations. One slot consists of seven OFDM symbols. The transmission takes up one PRB block of LTE carrier. There are the following physical channels: NPBCH - narrowband broadcast channel, NPDCCH - signaling channel, NPDSCH - for data transmission. Narrow-band synchronization signals NPSS and NSSS and narrow-band reference signal NRS are sent in the downlink channel.

In the uplink PRB block, single tone transmission with 15 and 3,75 kHz subcarrier raster or SC-FDMA multi-tone transmission with 15 kHz spacing is possible. For one tone transmission, subcarrier modulation π / 4-QPSK or π / 2-BPSK is used; for multi-tone transmission we have QPSK modulation. As a result, for a 15 kHz subcarrier interval, a single slot is divided into 7 OFDM symbols, each of which consists of 12 subcarriers and lasts 0,5 ms. At 3.75 kHz, each OFDM symbol consists of 48 subcarriers and lasts 2 ms. Only fixed PRBs can transmit NB-IoT signals. There are the following physical channels: NPRACH - narrowband terminal access channel to the base station, NPUSCH - narrowband data transmission channel.

2) Coverage extension

NB-IoT is designed for IoT devices located deep (in basements, technical infrastructure) or in remote locations. Because of this NB-IoT system should work it a 20 dB weaker signal than for GPRS, which gives a path loss of 164 dB.

To achieve this goal, two solutions were used: repetition and the ability to assign variable bandwidth in multi-tone transmission [4]. Repetitions occur in the uplink (NPRACH) and downlink (NPDCCH). Based on the received power reported by the UE, eNB (base station) sets the Coverage Enhancement (CE) level for the connection. The number of repetitions is associated with CE. There are three levels of Coverage Enhancement: CE0, CE1, CE2. The UE transmitter power is determined on the basis of received SNR. All transmission parameters, including the type of modulation and coding are transmitted in the NPDCCH [6].

3) Energy saving methods

Two power saving mechanisms for EU have been introduced: Power Saving Mode (PSM) and Extended / Enhanced Discontinuous Reception (eDRX). The DRX mode, as usual, is that the UE only receives frames containing calls. In eDRX mode, with no connection (Radio Resource Control - Idle), intervals between call monitoring by the UE may be up to 3 hours.

The UE may also enter PSM mode when the radio power supply is disconnected for a time agreed with the network. In PSM mode, the UE is unreachable from the network, but is registered on the network. The UE may resume the connection at any time. Sleep time in this mode can be up to 413 days [7].

4) Network architecture for the NB-IoT

We will take a look at the backbone network architecture to provide connectivity to the Cat-NB1 User Equipments (UE).

Architecture of the NB-IoT core network is based on evolved Packet Core (EPC) used by LTE

Data exchange between the network and the terminals is mainly divided into user plane and control plane. User plane sends user data based on the IP protocol, control plane transports connection control data and small user data such as SMS. New in NB-IoT is non-IP data delivery using control plane. However, for this data to go beyond the operator's network, a new intermediary element is needed. It is an SCEF (Service Capability Exposure Function) element that mediates the transport of small non-IP data between the UE and the application server (AS).

Thanks to SCEF the NB-IoT UE's can exchange non-IP data with application server , which was not found in classic LTE. The need for non-IP data transfer results from the main assumptions of narrowband IoT systems, which are designed to transmit very small amounts of data in order to save bandwidth and energy as well as to provide a much larger network capacity than in the case of traditional LTE. IP protocols are too redundant for sending typical telemetry data, e.g. consumption meter status or tamper status, because the amount of data needed to set up and maintain an IP session is many times higher than the information content. Without this approach, the implementation of NB-IoT would not be possible on a massive scale.

Most IoT devices transmit small amount of data sporadically, rather than in large data packets; therefore, the LTE core network also needs to evolve to better support IoT traffic profiles by providing more efficient signaling and resource management. [9]

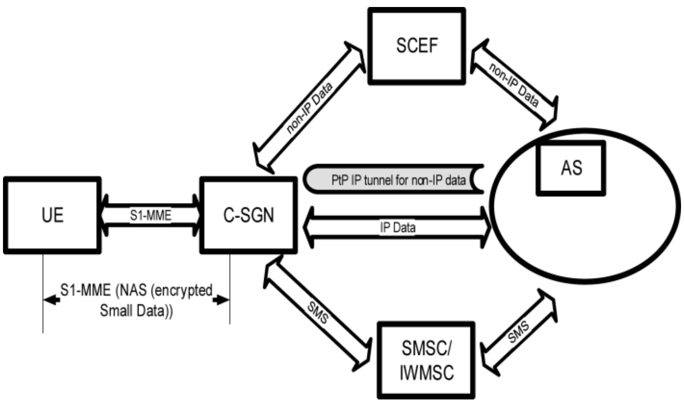

Fig. 2. E2E Small data flow [8]

Other NB-IoT L2 and L3 enhancements include the reduction of the maximum PDCP SDU and Control PDU sizes, from 8188 octets to 1600 bytes. This is a reasonable tradeoff as traditional internet traffic does not exceed 1500 bytes per IP packet. [10]

In NB-IoT, communication is divided into the control plane and the user plane. The control plane consists of protocols that control the radio access bearers and the connection between the UE and the network. The top most layer of the control plane is called Non-Access Stratum (NAS), which carries radio signaling between the UE and EPC, passing transparently through the radio network. NAS is responsible for authentication, security control, mobility management and media management. Access Stratum (AS) is a functional layer under the NAS, and in the control plane consists of the Radio Resource Control (RRC) protocol. RRC configures user and control planes according to the network status. There are two main states RRC, RRC Idle or RRC Connected. [10]

One of the solution, Data-over-NAS (DONAS), is mandatory and is a control plane optimization based on solution 2 proposed in [8]. DONAS enables transmitting data without having to activate an user plane, implementing only this option allows UE implementations with fewer requirements related to the user plane, such as the support for Unacknowledged Mode (UM) in RLC, multiple dedicated logical channels, DTCH, RLC re-establishment, DTCH). The second solution is an user plane optimization called RRC Suspend/Resume. This mode is optional and is based on solution 18 specified in [8]). RRC Suspend/Resume introduces enhancements to disable and restore the user plane in an efficient way. In the control plane optimization the data is sent over Non Access Stratum (NAS), directly from the Mobility Management Entity (MME) in the core network to the UE without interaction from the base station.[10]

Thanks to this type of user data transport there is no need to change and keep the RRC connected state by saving large amount of signaling data, the UE will also need less battery power.

B. LTE Cat M1 system

LTE Cat M1 (LTE-M) specified by 3GPP is an alternative technology to NB-IoT to support machine type communication (MTC). Release 13 describes “Bandwidth-reduced low-complexity (BL) LTE-M for machine type communication. It gives some advantages over NB-IoT like mobility, higher data rates and voice services (VoLTE) support. It expands variety of applications where LTE-M device can be applied and serve people (e.g emergency call triggered by motion sensor monitoring elderly people). While NB-IoT is recommended for stationary use such as smart metering applications, LTE-M is designed to be used for tracking purposes where handovers between base stations are required for moving objects. LTE-M is suitable for data transmission with maximum data rate up to 1 Mbit/s [11]. Both LTE-M and NB-IoT technologies uses frame retransmission techniques to increase coverage, however LTE-M signals are not power boosted contrary to NB-IoT. LTE-M technology is using existing LTE network and cannot be implemented as standalone either in guard bands. It always shares the synchronization and reference signals with standard LTE network, and occupies part of its bandwidth (1.4 MHz). It has an impact on network by reducing the capacity of mobile broadband internet access. One of positive features of LTE-M is use of “frequency hopping” within LTE subcarriers to make LTE-M more resistant to interference, fading and impact of LTE traffic.

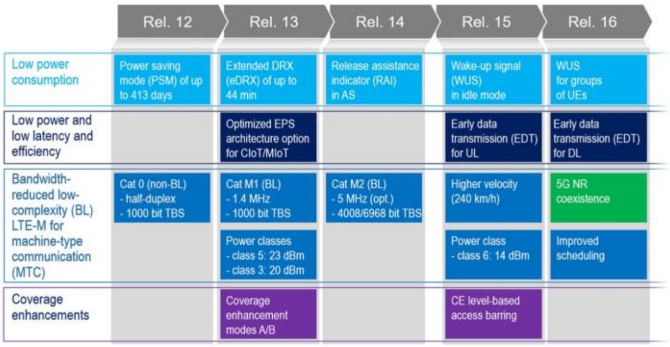

Fig. 3. 3GPP standard development

LTE-M devices just like NB-IoT ones are supposed to use as little power as possible to maximize its lifetime on single battery reaching 10 years. This is why power saving features like PSM, eDRX are commonly used.

For the LTE-M is specified two coverage enhancement modes: Mode A (32 repetitions) and Mode B (2048 repetitions) with QPSK modulation. Mode A is a mandatory feature for CAT-M1 whereas Mode B is an optional feature.

LTE-M technology requires a lot of testing both from network and device point of view. From network side - cooperation with classic LTE network, as they share the same infrastructure and outdoor/indoor coverage measurement need to be performed. In case of LTE-M modems we need to consider specific features, not so much important to classic LTE modems. For example, detailed analysis and optimization of power consumption under different configurations and operational models is highly recommend to ensure longest battery life. From end-to-end perspective VoLTE service is verified and latency measurement to guarantee reliable operation.

III. MEASURING TOOLS

To receive the NB-IoT signal (800MHz, channel 20), the LTE / NB-IoT test terminal from Quectel was used with the Qualcomm MDM 9206 chipset, connected via USB to a Samsung Galaxy S8 mobile phone on which the QualiPoc measuring software from Rohde & Schwarz was installed SwissQual AG [12]. From the telephone, it is possible to control the terminal, initiate communication, observe the signaling and connection parameters on an ongoing basis. You can also record signaling and connection progress in the phone's memory. During measurements, the terminal is powered by the telephone battery. Both devices form a convenient mobile measuring device. Recorded data blocks can then be analyzed on a computer with NQDI software from the same company and a list of selected parameters for further analysis can be obtained: NRSRP, NRSSI, NRSRQ, NSINR, Coverage Enhancement mode, data of the current base station, etc.

Fig. 4. NB-IoT measuring device

A single measurement comparing LTE and NB-IoT reception was made in the laboratory, without interference.

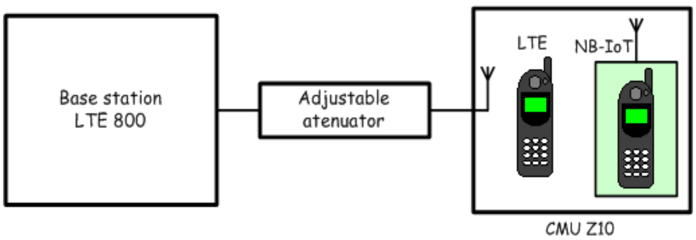

Fig. 5. Comparing LTE and NB-IoT reception

The above NB-IoT device and an additional LTE measuring telephone were placed in the CMU Z10 Rohde & Schwarz shielding box. The QualiPoc measuring program was running on both terminals. The antenna in the box was fed, through an adjustable attenuator, a signal from the Huawei LTE800 laboratory base station, which broadcast LTE and NB-IoT signals. Attenuator settings were changed, and both NB-IoT and LTE terminals recorded the transmission process.

Rohde & Schwarz TSME6 scanner was also used for the measurements. The TSME6 measures all radio frequency bands from 350 MHz to 6 GHz without any gaps. It is designed for drive and walk tests of all major wireless communications standards (GSM, WCDMA, LTE (FDD/TDD), LTE-M, 5G NR, NB-IoT, TD-SCDMA, CDMA2000, 1xEV-DO and WiMAX). Scanner allows the LTE uplink and downlink allocation analysis.

All bands defined for NB-IoT are covered by the scanner. Scanner supports three modes of operation of NB-IoT: in band, guard band and standalone. Scanner can detect eNodeB-ID, CI and cell ID.

Fig. 6. TSME6 scanner. Rohde & Schwarz [13]

TSME6 scanner allows to coverage measurements using synchronization signals: NSSS (Secondary signal power) and NSSS CINR (Carrier power to Interference and Noise Ratio) based on NSSS. In case of bad signal quality, the scanner allows to detect lack of coverage or interference.

Reference signal measurements for NB-IoT are: Reference Signal CINR (NRS CINR), Reference Signal Received Power (NRSRP), Reference Signal Received Quality (NRSRQ), Reference Signal RSSI (NRS RSSI). Scanner sensitivity (NSSS power) for physical cell ID decoding is -132 dBm and -142 dBm for reference signal power (NRSRP).

The results of measurements can be displayed on PC or smartphone via air interface.

IV. MEASUREMENTS RESULTS

Using the NB-IoT measuring equipment presented above, measurements were made in the staircase of the new part of building of the Faculty of Electronics and Information Technology of Warsaw University of Technology and measurements from a car in the suburban area near Warsaw, in the Piaseczno area. In both cases, the terminal was connected to the T-Mobile network. During the measurements active transmission was maintained by sending ping packets. The connection was recorded and then processed.

TSME6 scanner from Rohde & Schwarz was used to evaluate the number of stations received, signal levels, and possible interference. Such measurements were taken both in the staircase and outside in the vicinity of the University.

The staircase is completely concrete, without windows, with a relatively small number of doors. In the basement, on level -2, there is a passage to the garage, where measurements were also made.

Measurements on the stairs were made in two ways: moving slowly down from the 4th floor to the basement and stationary, where on each floor many measurements were made. Measurements outside were made from the car.

The results of stationary scanner measurements in the staircase are shown in Fig. 7.

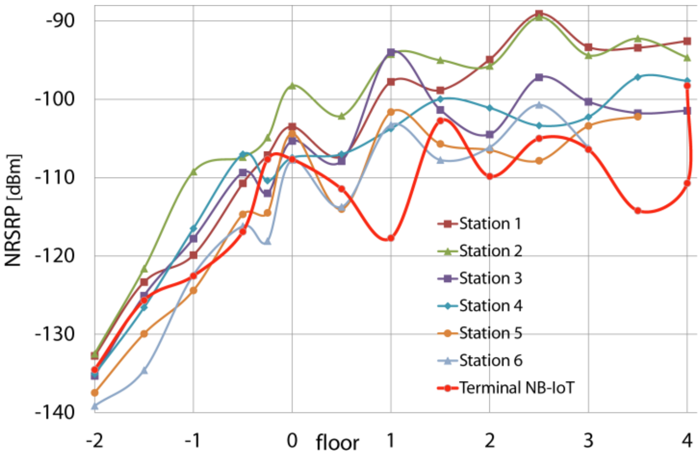

Fig. 7. Staircase. Stationary NRSRP measurement with a scanner. Results from the NB-IoT terminal are also shown

Six base stations were received. Stations 1 and 2 are strongest. The location of the station is shown on Fig. 8. NB-IoT terminal was receiving base station 1. The graph shows that below floor -1,5 could be no reception when the signal is below -130 dBm.

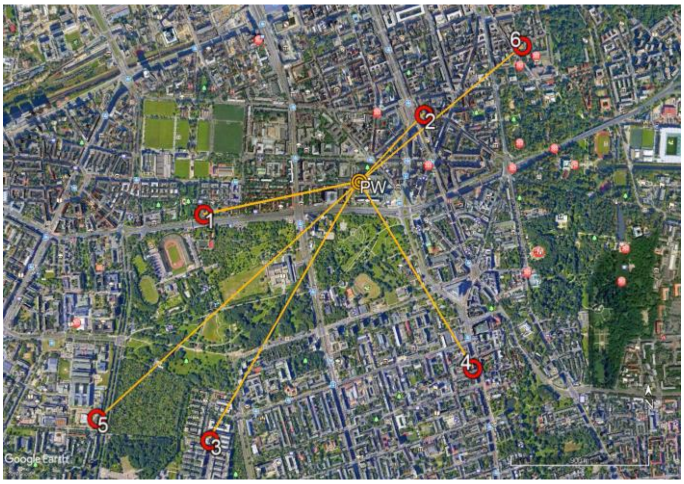

Fig. 8. Location of stations received in the staircase

Measurement in the garage showed that the received signals are on the scanner's sensitivity limit. There was no reception of stations 5 and 6. Fig. 9 shows the signal levels in the garage, much below -130 dBm.

Distances, azimuths of measured base stations to the University and azimuths of maximum radiation of base stations antennas were shown in Table I.

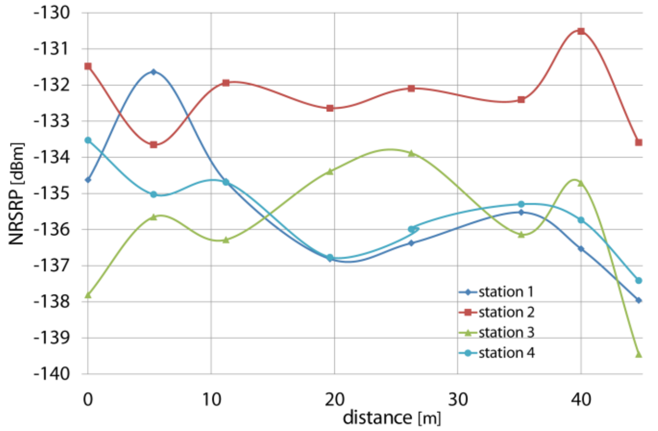

Fig. 9. NRSRP in the garage (level -2)

The NB-IoT termnial in the garage did not work.

A similar but dynamic (slowly moving down) measurement was performed with the NB-IoT terminal. The terminal selected station 1 and established the connection. During the measurements active transmission was maintained by sending ping packets. The level of the received signal is shown in Fig. 10.

TABLE I
RECEIVED BASE STATIONS

Base station	CI	Distance [km]	Azimuth to the University	Azimuth of max base antenna
1	46409839	1,03	79,86	70
2	46350448	0,59	225,78	185
3	46460271	1,88	32,38	40
4	46341233	1,37	328,45	310
5	46364783	2,23	50,32	70
6	46367344	1,35	232,66	190

The signal level depends on the storey, between the floors is weaker, because there are almost no holes in the staircase wall. At level 0, you can see a significant increase in level, because you go near external doors. Then the signal decreases strongly and at level -1 the connection is broken. We have extended connection modes on the whole route. The terminal transmitted with a maximum power of 23 dBm.

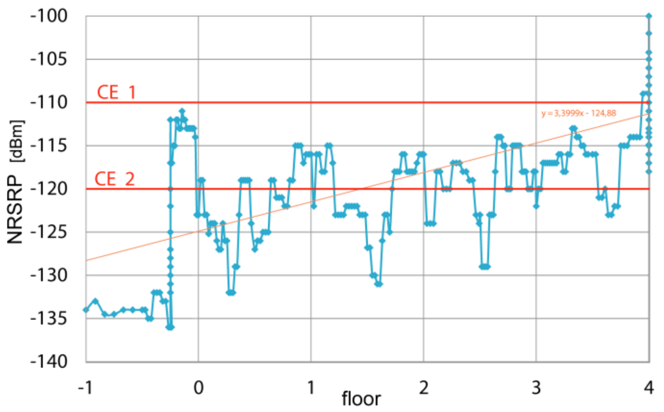

Fig. 10. NRSRP on the staircase, slow moving down. Signal levels at which the CE mode is changed are indicated

Ping packets were sent to maintain connection with the base station during measurements with the NB-IoT terminal. Fig. 11 shows the relationship of RTT delay to the signal level, which can be considered as an assessment of the quality of transmission. The delay does not depend on the signal level, but it takes several values depending on the changing conditions on the staircase floors.

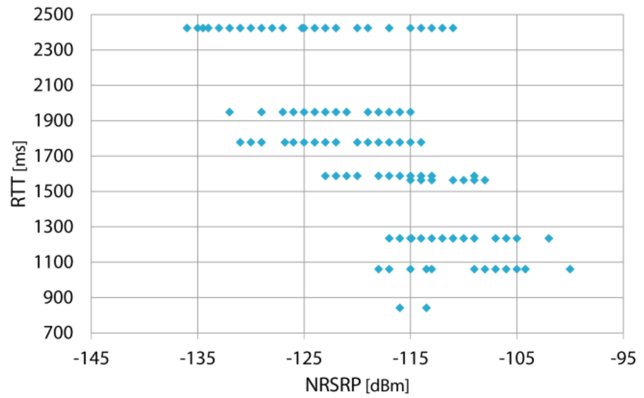

Fig. 11. Average delay of ping packets on a staircase. Each measurement contained 100 packages

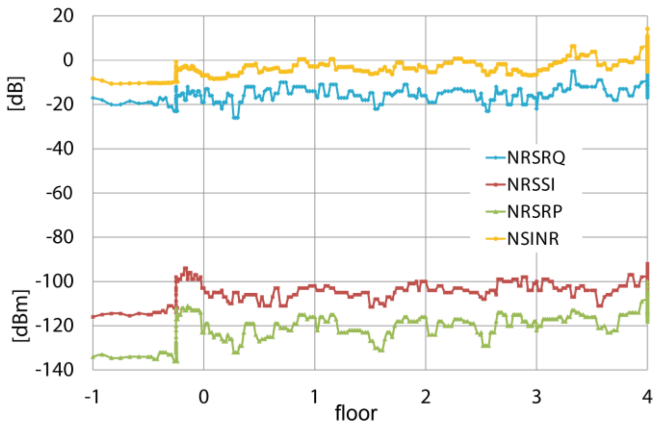

Fig. 12. Other transmission parameters at staircase.

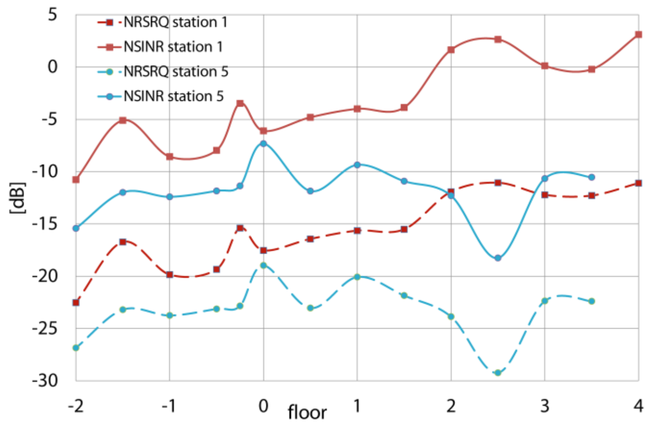

Fig. 13. Other transmission parameters at staircase. Scanner measurements

NRSRQ value equal to NRSRP / NRSSI can be one of the measures of connection quality. NB-IoT terminals can use any of these quantities to choose a base station. Fig. 12 shows these parameters for dynamic measurements at staircase with NB-IoT terminal (connected to base station 1).

As can be seen, the range limit occurred at NRSRQ around -19 dB, with NRSRP below -130 dBm.

Similar results were obtained in the staircase for static scanner measurements. The measurement results from two base stations are shown in Fig. 13. Also these results show that the connection to base station 1 will be difficult below level -1,5. Connection to a weaker base station 5 is not possible.

Interesting results were obtained with external measurements in Piaseczno. NB-IoT terminal was used for this measurements.

The measurement route is shown on Fig. 14. The level of signal received on the route is plotted on Fig. 15 as a function of decimal time (the measurement hour is given as a fraction of the day, e.g. 10:27:05 is 0,435474537 part of the day). There is good reception from 9 base stations along the entire route.

Almost all the time the NB-IoT terminal was in CE0 mode. From the signaling messages recorded, it can be seen that when the level of the received signal drops, the terminal briefly switches to CE1 or even CE2 mode. Changing the mode it disconnects and reconnects to the base station. However, in this case, the re-selection occurs and the terminal selects a better base station.

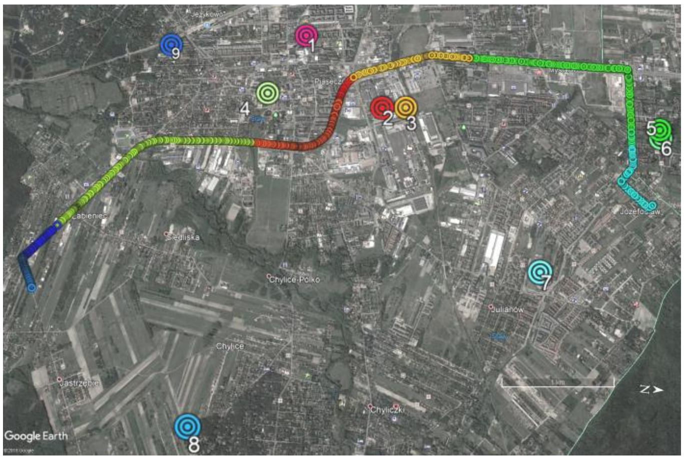

Fig. 14. Measurement route in Piaseczno and location of base stations. The colors indicate the connection position with the corresponding base station

The drawing indicates such moments. In NB-IoT there is no handover, however the connection process looks similar to handover. Fig. 15 also shows the power transmitted by the NB-IoT terminal. The relationship between the transmitted power and the NRSRP level is clearly visible. Locating terminals in locations requiring low transmit power can be beneficial for energy savings.

During these measurements, ping packets were also sent to maintain the connection with the base station. The distribution of RTT delays is shown in Fig. 16. As in the case of staircase measurements, the delay does not depend on the NRSRP, but here it changes little over the entire measurement route. This is completely different compared to staircase measurements.

A measurement was made in the laboratory to assess the effect of channel attenuation on LTE and NB-IoT transmission. As has been said (Fig. 5), the signal from the laboratory base station was connected to LTE and NB-IoT terminals separated from the environment. An adjustable attenuator modeled channel attenuation, identical for both terminals. From the data recorded by both terminals, it was found that the LTE telephone lost connection at 104 dB attenuation and the NB-IoT terminal at 123 dB. Thus, the NB-IoT terminal worked with 19 dB higher route attenuation. The assumed value in the standards is 20 dB.

Furthermore, scanner measurements were taken to assess the NB-IoT radio propagation of NB-IoT in the urban area. Three base stations were selected at different distances from the University, such located that it is possible to move by streets between the base station and the University approximately in a straight line. Station 1, 2 and 4 were selected (Fig. 8).

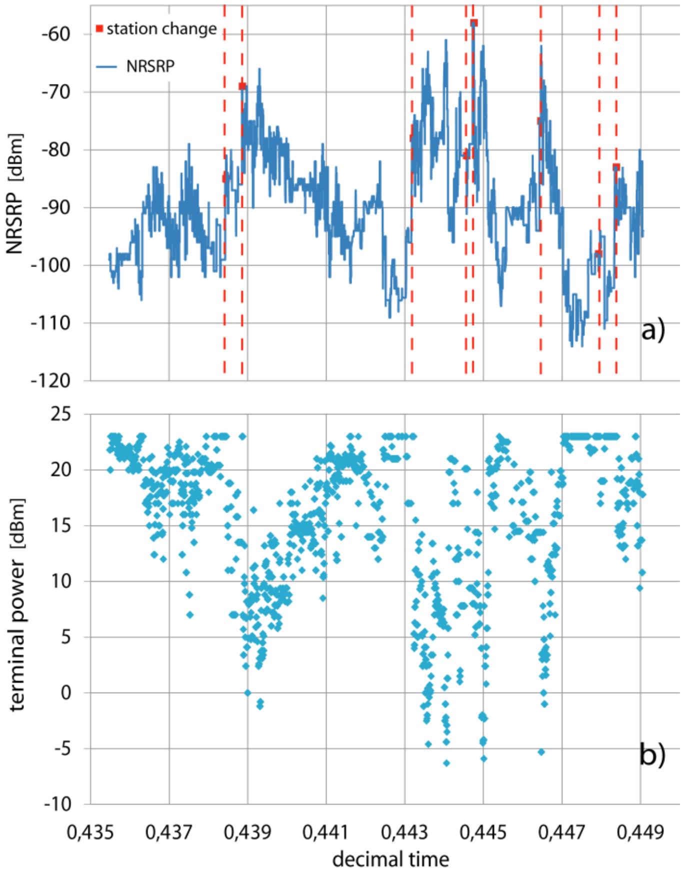

Fig. 15. Measurement results on the route in Piaseczno as a function of decimal time. a) NRSRP received signal level, b) NB-IoT terminal power

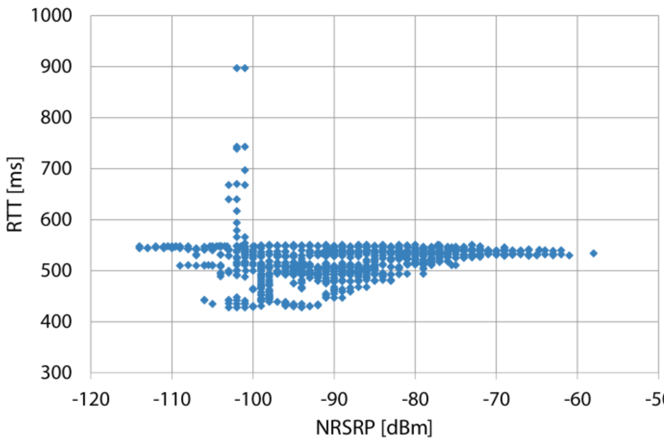

Fig. 16. Average ping packet delay for measurements in Piaseczno

On selected routes the base station signal measurements were made with a scanner from a car. The results are presented in Fig. 17.

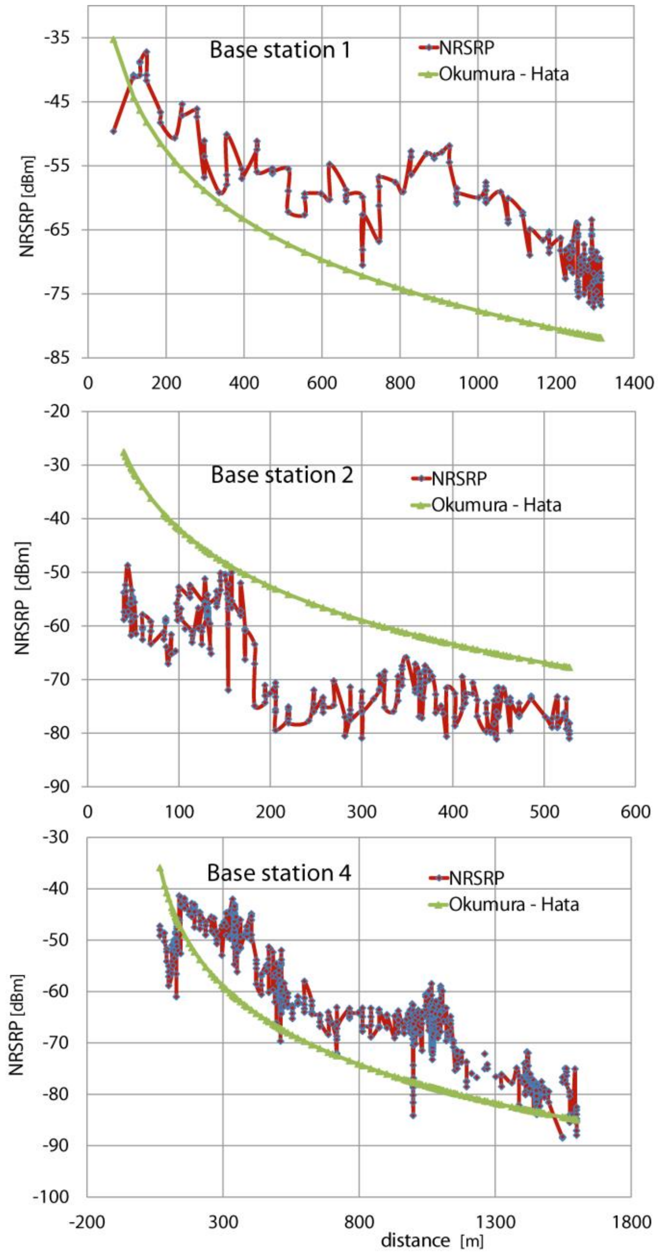

Fig. 17. Base stations signal level. NRSRP

On the charts there are also values from a typical Okumura-Hata model for metropolitan areas, for frequency in the 800 MHz range, 30 dBm transmitter power, 17,5 and 2 dBi antennas directivity, and 25 and 1.2 m antennas heights.

Thus, this model, perhaps with minor modifications, may be useful for planning NB-IoT systems.

CONCLUSION

The NB-IoT terminal was tested in a normally functioning cellular network in guard-band transmission. It was found that, according to the assumptions, it is possible to work with route suppression higher by almost 20 dB than in LTE. The terminal provides transmission in rooms, including underground. The terminal has proven itself as a mobile device. It provided a continuous connection with good quality in a moving car, in a suburban area.

In concrete basements there may be problems with NB-IoT transmission. The received power falls quickly below -130 dBm when transmission is interrupted. It has been confirmed that scanner measurements can be helpful when planning NB-IoT networks.

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