Experimental Performance Evaluation of NB-IOT Deployment Modes in Urban Area

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***Abstract*:** Narrow-band Internet of Things is a new promising radio technology standard that addresses the requirements of the IoT. The technology provides improved indoor coverage, support of massive number of low data rate devices, low delay sensitivity, ultra-low device cost, low device power consumption and optimized network architecture. The technology can be deployed in three different operational modes: (1) in-band, (2) guard-band, or (3) standalone in dedicated spectrum. The choice of NB-IoT deployment scenario has a significant impact on the quality and performance of the network.
In this article, presented the results of an experimental study of the performance of all three scenarios for NB-IoT deploying in a real working cellular network under equal operating conditions for consideration. The following parameters chosen as an assessment measure: radio coverage, network capacity and user experience. The research shown that exact the standalone mode provide the best performance for these parameters. In addition, we have confirmed that all three NB-IoT scenarios coexist perfectly on 2G/4G networks and satisfy the original requirements of 3GPP's in deep coverage and robust quality of network service.

***Keywords*:** NB-IoT, deployment mode, network quality, network performance.

1. Introduction

In 2016, the 3rd Generation Partnership Project (3GPP) introduced the Narrow-band Internet of Things (NB-IoT) as a new cellular radio access technology developed in Release 13 (LTE Advanced Pro) [1]. The technology designed to connect wireless IoT devices with low data transmission volumes over long distances. It is mainly used for low power, low rate scenarios that require deep coverage, and a massive volume of connections (more than 100k connections per carrier).

The NB-IoT is standardized based on existing cellular standards and supports almost all frequency bands intended for 2G (GSM), 3G (UMTS), 4G (LTE), with preference for band 20 (800MHz), band 8 (900MHz) and band 3 (1800MHz). Higher frequencies rarely using for NB-IoT due to the greater signal attenuation during long distance transmission. A complete list of supported frequencies presented in TS 36.101 Release 13-15 [2].

The advantage of this technology is high spectral efficiency due to the use of a small bandwidth (BW) of 180 kHz, while for LTE technology it ranges from 1.4 MHz to 20 MHz. The ability to implement NB-IoT over existing 2G/3G/4G networks without the necessity to obtain the permission to use radio frequencies for the new technology, and the ability to reuse the existing infrastructure of mobile networks [3] also adds the attractiveness to this technology and accelerates the development of NB-IoT networks.

According to GSMA data [4] as of November 2020, more than 155 IoT networks are built based on cellular networks communication; of which 105 are networks using NB-IoT technology (Fig. 1).

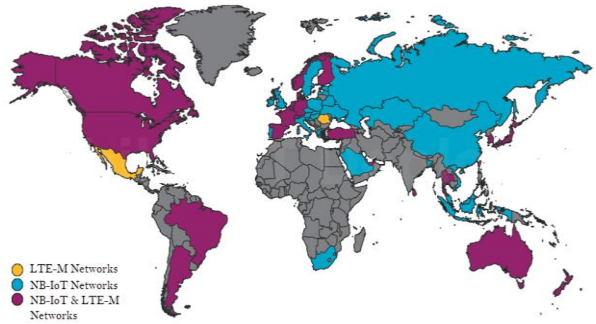

Figure 1. Use of 3GPP IoT technologies in the world

In the 3GPP TR 45.820 [1] specification, states that NB-IoT technology can support three scenarios of the radio frequency spectrum using (Fig. 2) in mobile networks, namely:

- standalone mode, in which use the existing free resources of the GSM spectrum based on frequency refarming (replacement) principles;
- in-band mode, in which the existing 4G resource blocks with bandwidth of 180 kHz allocating for NB-IoT technology;
- guard-band mode. In this scenario, for the NB-IoT deployment using excess spectrum of the frequency channel within the dedicated channel of 4G.

The presence of three scenarios explained by the fact that initially the NB-IoT standard was developed taking into account the requirements of full compatibility with already existing cellular network standards [5].

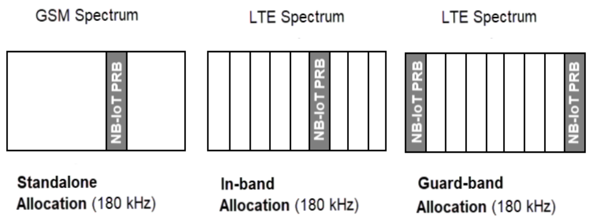

Figure 2. Deployment scenarios of NB IoT technology, adopted from [15]

The choice of a suitable scenario of NB-IoT technology deploying on an existing cellular network is very important, since it exerting significant impact on the main parameters of network quality, network performance, deployment speed, and infrastructure costs [6, 7]. Therefore, it is necessary for mobile operators to understand in advance, which of the NB-

IoT scenarios will be the most preferable for deployment in the mobile network and will help to achieve the best balance between mentioned criteria. However, to conduct a technical assessment of NB-IoT deployment scenarios, it is sufficient to consider the first two criteria – network quality and network performance parameters. These two criteria are used as the basis for selecting indicators for evaluating the NB-IoT network in Section 2.

Some previous studies have already investigated NB-IoT technology, its deployment modes and their features, as well as ways to measure and evaluate their effectiveness on mobile networks. Below are the most interesting ones.

For the beginning, a detailed description of the NB-IoT basics and deployment scenarios of it presented in articles [5, 8, 9]. In it the authors of the study theoretically proved that each scenario meets the strictest requirements of the 3GPP specification [1] for deep indoor coverage (Maximum Coupling Loss (MCL) = 164 dB), supports up to 52 thousand devices, provides low latency (> 10s) and battery life of NB-IoT devices up to 10 years.

The QoS and NB-IoT performance parameters used to analyze deployment scenarios are reflected in research papers [10] - [14]. Thus, in [10] the authors conducted a comparative analysis of several QoS parameters to assess the real-life performance of NB-IoT and system-level simulations. The authors recommend to including to the most relevant QoS parameters follows: MCL, uplink and downlink throughput, data rate and exception report latency. The research conducted only for the guard-band deployment scenario.

Authors Hoglund A., Lin X. et al. in a research paper [11] also focused on studying of NB-IoT deployment in the 4G-frequency guard-band, performed an analysis of mutual interference between IoT technology and the 4G basic mobile network.

In [12], the authors went further and researched into the NB-IoT network performance, namely the throughput, the possible number of connected terminals and latency, using the healthcare monitoring system as an example. Comparative analysis was performed using Monte Carlo simulation for in-band and stand-alone scenario of spectrum using. The performance of the in-band scenario turned out to be worse than the stand-alone scenario due to the presence of LTE control information in the first one. In addition, Mangalvedhe et al. [13] proved that for the in-band scenario occurs happen co-channel and adjacent channel interference on the existing LTE network. The occurrence of interference and large path loss can lead to degraded network coverage, but it can be overcome through PRB blanking in non-NB-IoT cells.

In [14] the authors compare three NB-IoT deployment scenarios in terms of coverage, occupied bandwidth, spectrum and delay. The authors note that in-band deployment mode provides the worst performance in terms of coverage and capacity compared to standalone and guard-band deployment modes, but the spectral efficiency of this scenario is much higher. Unfortunately, presented information is compressed and the nominal values of the exponents not shown in the work.

We summarize the related work in NB-IoT in Table 1.

Table 1. Related work

Area	Related work
NB-IoT Technology Overview	Technical Report [1] NB-IoT Basics [5], [8], [9] IoT Architecture [22]
Performance Analysis	[10] – [14]
Description of the Deployment Mode	Guard band [10], [11], [14] In-band [12] – [14] Standalone [12], [14]

The listed above studies made significant contributions to the research of NB-IoT deployment scenarios specifics. However, to this day lacking the performance studies for all three NB-IoT deployment scenarios on a single real cellular network under equal operating conditions, taking into account key network performance and quality parameters.

The main contribution of the paper are as follows:

1. Presented a sequential review of previous studies literature of the deploying NB-IoT technology specifics;
2. Described in detail the methodology used in this study for testing NB-IoT in a real cellular network in the 900MHz range;
3. Presented the results of an experimental study of three deployment scenarios on an existing cellular network;
4. Presented the main conclusions on the choice of the most optimal scenario for the deployment of NB-IoT based on the results.

The remainder of the paper is structured as follows. In section 2 describes in detail the used testing methodology, and defines the main parameters for studying NB-IoT implementation scenarios. In section 3 presents the test results and in section 4 presents the summary results.

2. Materials and Method

2.1 Test Methodology

The study of the NB-IoT network performance for each deployment scenario carried out on the existing 2G / 4G networks of the Kazakhstan mobile Operator A.

The research methodology includes three tasks:

- reproduction of the most realistic conditions for NB-IoT technology functioning on 2G/4G networks;
- measurement of the main network parameters within the provision of NB-IoT services for each scenario: (1) in-band, (2) guard-band, (3) standalone;
- comparison and analysis of the obtained researching results.

NB-IoT testing conducted in an urban cluster area consisting of 12 Base Transceiver Stations (BTS). The coverage area of base stations was 24.5 km^2. Testing details shown in Table 2.

The BTS transmission power for the NB-IoT deployed in guard band and in-band is only 35 dBm (table 2), which may be too low to achieve good performance compared to the 43 dBm used in NB-IoT standalone mode.

Since NB-IoT technology developed taking into account compatibility with existing standards of cellular networks, so the experiment carried out with reuse of the existing network architecture (Fig. 3) and equipment (hardware) without additional costs for infrastructure modernizing [13]. A software upgrade also not required, since on BTS installed the latest available SingleRAN16.1 version that complies with the 3GPP standard Release 16.1 [15] and supports NB-IoT functionality.

Table 2. Test assumptions

Parameter	Variable
Working mode	(1) Standalone (2) In-band (3) Guard band
Archictype	Urban
Scenario	36 sectors (12 sites) operating in 900 MHz
System Bandwidth	10MHz (in-band, guard-band), 200kHz (standalone)
NB-IoT operating Bandwidth	180 kHz
BTS transmit power for NB-IoT	35 dBm (in-band, guard-band), 43dBm (standalone)
Intersite distance	1053 – 1683 m
Antenna configuration	BTS: 1 Tx, 2 Rx; UE: 1 Tx, 1 Rx
LTE Cell load	>85%
Available resources	1 PRB per device (180 kHz)
BTS receiver noise figure	3 dB
Testing methodology	Statistical data collection Drive-test measurement

At present times, the most promising area of NB-IoT technology application is Remote Metering Applications, where NB-IoT technology allow to data collection and remote control for suppliers of electricity, heat energy, water utilities, etc. [16-17]. This particular business case taken as the basis for testing the performance of an NB-IoT network when using different deployment modes (Fig. 3).

The results obtained based on statistical data and drive test measurements (static measurement of the actual network parameters in the various points of the route in the network coverage area).

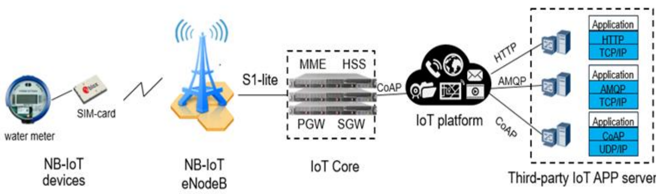

Figure 3. Network architecture of NB-IoT network for water meter application

Statistical data collected from the mobile network within 30 calendar days. The collection of statistics holding hourly, mainly selecting the busy hours (BH) of the network load, which allows analyzing the impact of each NB-IoT scenarios in close to real operating conditions of 2G / 4G networks.

2.2 Network KPIs

The following key performance indicators (KPI) selected as the main parameters of NB-IoT network performance and quality parameters:

i. Radio coverage - evaluates the coverage of IoT services to achieve acceptable QoS (Quality of Service). Determined by the Reference Signal Received Power (RSRP) parameter. The RSRP value is lower the further the UE is from the base station, and vice versa [18]. Thus, the distance of the UE from the BTS directly affects the RSRP;

ii. Network quality - determines the quality of the network, namely the level of the useful -signal, subject to the influence of third-party interference and interference. Described by the Signal to Interference plus Noise Ratio (SINR) parameter. The higher the SINR value, the better signal and network quality in general. With a negative SINR value, the noise level exceeds the desired signal level. For SINR, there is no direct dependence on the distance between UE and BTS.

SINR and RSRP parameters are one of the main KPIs designed to measure the radio conditions of 4G networks [19];

iii. User experience - determines the quality of the provided communication services from the client's point of view, and consists of such parameters as uplink/downlink (UL/DL) user throughput, cell edge throughput, data traffic, call drop rate, etc. As far as we are talking about a technology designed to transfer small amounts of data and not critical to connection the disconnection, so we will restrict ourselves to measuring UL/DL user throughput.

3. Results and Discussion

In this section presents the results of an experimental study of cellular network performance for three scenarios of NB-IoT deployment within the provision of IoT services. The analysis carried out based on measuring the previously presented parameters of RSRP, SINR, UL and DL user throughput in accordance with the developed testing methodology. These metrics are most suitable for describing the performance of NB-IoT technology [10].

3.1 Radio Coverage Analysis

RSRP is a linear average of the power in Watts of the resource elements carrying Narrowband Reference Symbols (NRS) in a given frequency BW. Since NB-IoT downlink is based on a 15kHz carrier spacing, the RSRP is the power of a single 15kHz NRS [10]. NB-IoT RSRP reporting range is "-44…-140" dBm.

The measurements were taken at a distance approximately of 1.2 km from the BTS. The obtained RSRP indoor measurements summarized in Table 3.

Table 3. RSRP indoor measurement report

Method	Parameter	Standalone mode	Guard band mode	In-band mode
Test results based on UE measurement	Avg DL RSRP, dBm	-120.21	-121.98	-125.01
	Max DL RSRP, dBm	-95.57	-97.91	-98.51

Table 3 shows that the best result is achieved when using standalone mode (RSRP = -120.21dBm). The worst result for the level of the received RSRP signal at a distance of 1.2 km

from the base station shows an in-band scenario (-125.01 dBm). When using the in-band scenario, the average RSRP is degraded by -3.03dBm versus guard band and -4.8dBm versus standalone. The reason is the presence of high losses on the way and corresponding interference arising from adjacent RB blocks for LTE and NB-IoT.
There is no visible interference for the standalone and guard band deployment.
As the UE moves away from the BTS, the difference in RSRP values for three NB-IoT deployment scenarios will increase and will peak at the cell edge. In a real environment, there are enough factors that affect the coverage area and require attention during the network planning stage. These include: architype (urban / suburban / rural), BTS serving area (existing LTE / GSM coverage distance), available spectrum, BTS transceiver power, the sensitive of UE's receiving antenna, etc.

3.2 Network Quality

SINR is the ratio of the useful signal level to the noise and interference level. SINR using as an indicator of network quality, however, it is not one of the mandatory KPIs defined by 3GPP. This is due to the fact that SINR reported by the user terminal during an active session and it`s not reported to the cellular network. SINR value measured in dB.
The relation between SINR and RSRP defined by the formula (1):

$$SINR = \frac{RSRP\ [W]}{P_{I,15kHz} + P_{N,eff,15kHz}} [dBm], \quad (1)$$

where $P_{I,15kHz}$ is the interference power from external sources, and $P_{N,eff,15kHz}$ is the effective noise power.

For IoT devices, SINR and RSRP are measured on the served cell only during an active connection. In NB-IoT, this happens because the standard does not support smooth mobility and handover, and it makes no sense to measure signals from neighboring cells during a drive test.
Figure 4 shows the average DL SINR values for different NB-IoT deployment modes. The best result is shown by the standalone mode (-7.8dB), followed by the guard band (-8.3dB) and in-band with a slight lag (-8.5dB).

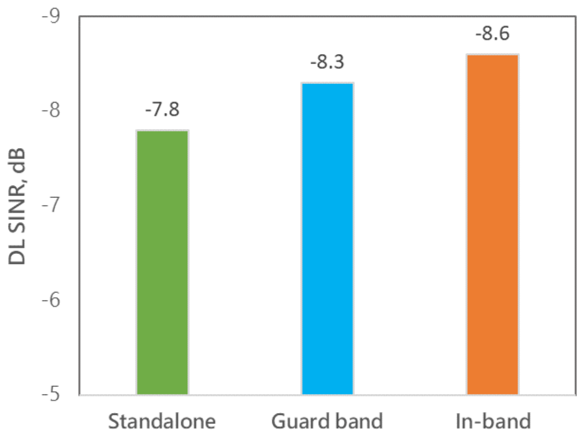

Figure 4. Downlink SINR measurements for different NB-IoT deployment modes

The recommended SINR value for acceptable network operation is greater than 0 dB; with a negative value, the interference level exceeds the level of the useful signal, which is a frequent at the cell border. However, in real-world conditions, the NB-IoT SINR reporting range can vary from – 20 dB to 20 dB. Since we primarily set out to test NB-IoT KPIs as close as possible to real conditions, DL SINR measurements carried out at a point with an RSRP indoor coverage level of -130dBm, i.e. at the edge of the cells serving.

3.3 User Experience

Throughput is a parameter used by mobile operators to determine average data rates and calculate the required capacity per sector of a base station.
DL Throughput is the average downlink data rate of the base station to the end user, kbit/s [kbps]. Calculated at the cell, sector or BTS level. It is calculated as the ratio of the data total amount to the sum of the data transmission time values for all subscriber terminals. The formula for calculating the parameter shown below:

$$Avg.DL.Thrp = \frac{\sum_{i=1}^{25} L.Thrp.bits.DL}{\sum_{i=1}^{25} L.Thrp.Time.DL} [kbps], \quad (2)$$

where $\sum_{i=1}^{25} L.Thrp.bits.DL$ is the sum of all bits information, transmitted in the direction downlink per cell, and $\sum_{i=1}^{25} L.Thrp.Time.DL$ is the time used to send the information.

The results of a comparative analysis of the average DL user throughput for three NB-IoT deployment scenarios shown on Figure 5. It can be seen that the average DL throughput for standalone mode is 14.90 kbps per user, while for guard band and in-band scenarios the parameters lower - 11.09 kbps and 9.82 kbps, respectively. Theoretically, the maximum user throughput reaches 20 kbps under ideal radio conditions for single tone mode. The results of experimental confirmed by previous studies [20]. For the average value of User Throughput influenced such factors as: cell load, user / UE quantity, distance from user / UE to serving cell, etc.

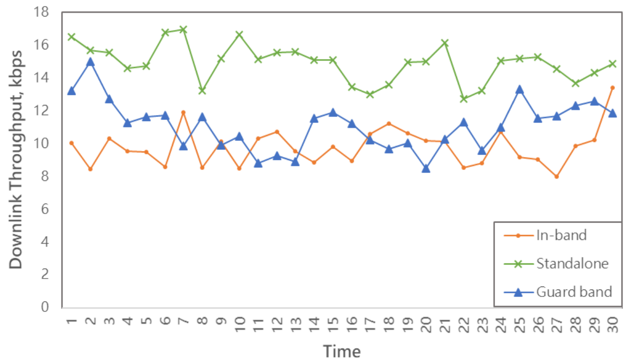

Figure 5. Measurements of Downlink Throughput in Busy Hour (BH) during period of 30 days

UL Throughput is the average data speed rate of the base station to the end user on the line "Up", kbps. Calculated at the cell level and above. It calculated as the ratio of the total data amount to the sum of the time values of data transmission for all subscriber terminals.

$$Avg.UL.Thrp = \frac{\sum_{i=1}^{25}(L.Thrp.bitsUL - L.Thrp.bitsUE.UL.LastTTI)}{\sum_{i=1}^{25} L.Thrp.bitsUE.UL.RmvLastTTI}[kbps], \quad (2)$$

where $L.Thrp.bits.UL$ is the sum of all bits of information transmitted in the direction uplink per cell, $L.Thrp.bits.UE.UL.LastTTI$ is the total Data Volume excluding data transferred in the Time Transmission Intervals (TTI) emptying the buffer, and $L.Thrp.bits.UE.UL.RmvLastTTI$ is the time used to send the information excluding last TTIs [21].

Uplink Throughput testing showed that, on average, the obtained values are the same for all three NB-IoT deployment scenarios: standalone - 6.76kbps, guard band - 6.40kbps, in-band - 6.05 kbps (Fig. 6). Therefore, the type of deployment scenarios has immaterial effect on the UL User Throughput

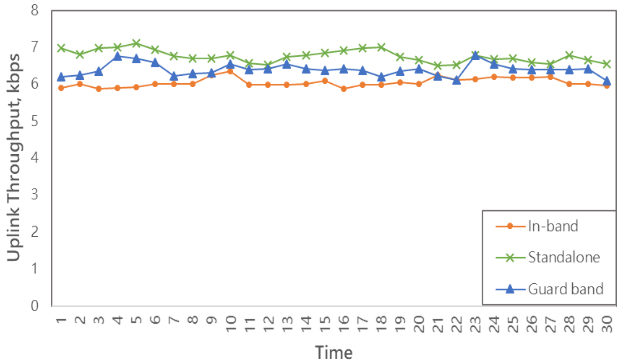

Figure 6. Measurements of Uplink Throughput in Busy Hour (BH) during period of 30 days

4. Conclusions

The study presents the results of evaluating the performance of NB-IoT technology for three deployment modes: (1) in-band, (2) guard-band and (3) standalone. The scenarios variability is due to the 3GPP requirements to the possibility of implantation NB-IoT in any existing cellular network. Accordingly, each of the scenarios has its own peculiarities.

In this paper, NB-IoT deployment modes are compared in terms of radio coverage, network quality and user experience, and evaluated using RSRP, SINR, UL/DL throughput parameters. The research has shown that exact the standalone deployment mode provides the best performance for these parameters due to the allocated frequency resource. However, to use it, it is necessary to make the refarming for the 200 kHz of GSM spectrum, which is not always possible due to the high cost of low frequencies used for a 2G network.

In the case of using a 4G network for the implementation of NB-IoT, it is recommended to use in-band and guard-band deployment modes. These two modes have slightly worse performance compared to standalone mode due to deployment within the existing spectrum, low BTS transmission power, and the presence of interference, but meet the basic requirements of 3GPP specification.

The study shown that radio coverage and network quality for in-band mode is on average 3% worse, and DL Throughput is 11% lower compared to guard-band deployment mode. As a result, fewer subscribers with good signal strength can be connected at the base station's service edge using in-band mode. However, the choice of the NB-IoT deployment mode does not affect the UL User Throughput value in any way and has a stable value for all three modes.

In addition, our research confirmed that all three of NB-IoT technology deployment scenarios coexist perfectly on 2G/4G networks and meet the requirements of 3GPP`s in deep coverage and robust quality of network service.

References

[1] 3GPP TR 45.820. Cellular System Support for Ultra Low Complexity and Low Throughput Internet of Things (CIoT), Technical Report, 2015.
[2] 3GPP TS 36.101. Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception, Technical Report, 2017.
[3] H. Malik, M.M. Alam, A. Kuusik, Y. Le Moullec, S. Pärand, "Narrowband Internet of Things (NB-IoT) for Industrial Automation," Wireless Automation as an Enabler for the Next Industrial Revolution, pp. 65-87, 2019.
[4] (2021, January). Mobile IoT Network Launches, GSMA Report, 2020. [Online]. Available: https://www.gsma.com/iot/mobile-iot-commercial-launches/
[5] R. Ratasuk, B. Vejlgaard, N. Mangalvedhe, A. Ghosh, "NB-IoT system for M2M communication," 2016 IEEE Wireless Communications and Networking Conference, Doha, Qatar, pp. 428-432, 2016.
[6] J. Afzal, "NB-IoT - The choice of Frequency, Deployment Mode and Coverage," 2017.
[7] J. Abdujalilov, K. Turzhanova, S. Konshin, A. Solochshenko, B. Yakubov, "Analysis and improvement of the methods used for performance assessing of 4G network with NB-IoT technology for three scenarios of spectrum use in the 900 MHz range," 2020 International Conference on Information Science and Communications Technologies (ICISCT), Tashkent, Uzbekistan, pp. 1-4, 2020.
[8] A. D. Zayas, P. Merino, "The 3GPP NB-IoT system architecture for the Internet of Things," 2017 IEEE International Conference on Communications Workshops (ICC Workshops), Paris, France, pp. 277-282, 2017.
[9] K. F. Muteba, K. Djouani, T. O. Olwal, "Opportunistic Resource Allocation for Narrowband Internet of Things: A Literature Review," 2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE), Istanbul, Turkey, pp. 1-6, 2020.
[10] A.P. Matz, J.-A. Fernandez-Prieto, J. Cañada-Bago, U. Birkel, "A Systematic Analysis of Narrowband IoT Quality of Service," Sensors 2020, vol. 20, no. 6, pp. 1-2, 2020.
[11] A. Hoglund et al., "Overview of 3GPP Release 14 Enhanced NB-IoT," IEEE Network, vol. 31, no. 6, pp. 16-22, 2017.
[12] H. Malik, M. Mahtab Alam, Y. Le Moullec, A. Kuusik, "NarrowBand-IoT Performance Analysis for Healthcare Applications," The 8th International Conference on Sustainable Energy Information Technology (SEIT-2018), Porto, Portugal, pp. 1077-1083, 2018.
[13] N. Mangalvedhe, R. Ratasuk, A. Ghosh, "NB-IoT deployment study for low power wide area cellular IoT," 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Valencia, Spain, pp. 1-6, 2016.
[14] D. Xue, H. Xu, P. Li, "An Indoor 3D Positioning Technology Based on NB-IoT," Advances in Intelligent Systems and Computing, vol. 927, pp. 35-43, 2019.
[15] 3GPP TR 21.916. Release Description. Release 16, Technical Report, 2020.
[16] O. Vermesan, P. Friess, "Internet of Things Applications: From Research and Innovation to Market Deployment," River Publishers Series in Communications, pp. 1-373, 2014.
[17] M. Pennacchioni, M. Di Benedette, T. Pecorella, C. Carlini and P. Obino, "NB-IoT system deployment for smart metering:

Evaluation of coverage and capacity performances," 2017 AEIT International Annual Conference, Cagliari, Italy, pp. 1-6, 2017.

[18] S. Pramono, L. Alvionita, M. Danang, M.E. Sulistyo, "Optimization of 4G LTE (Long Term Evolution) Network Coverage Area in Sub Urban," AIP Conference Proceedings, vol. 2217, no. 1, pp. 1-9, 2020.

[19] F. Afroz, R. Subramanian, R. Heidary, K. Sandrasegaran, S. Ahmed, "SINR, RSRP, RSSI and RSRQ Measurements in Long Term Evolution Networks," International Journal of Wireless & Mobile Networks (IJWMN), vol. 7, no.4, pp. 113-123, 2015.

[20] S. S. Basu, A. K. Sultania, J. Famaey, J. Hoebeke, "Experimental Performance Evaluation of NB-IoT," 2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Barcelona, Spain, pp. 1-6, 2019.

[21] V. Buenestado, J. M. Ruiz-Avilés, M. Toril, S. Luna-Ramírez and A. Mendo, "Analysis of Throughput Performance Statistics for Benchmarking LTE Networks," IEEE Communications Letters, vol. 18, no. 9, pp. 1607-1610, 2014.

[22] N. Almrezeq, L. Almadhoor, T. Alrasheed, A.A. Abd El-Aziz, S. Nashwan, "Design a secure IoT Architecture using Smart Wireless Networks," International Journal of Communication Networks and Information Security (IJCNIS), vol. 12, no. 3, 2020.