# ABSTRACT

to the thesis research, submitted for the PhD degree in
specialty 6D071900 – «Radio engineering, electronics and telecommunications»

by
TURZHANOVA KARINA MURATOVNA

A subject of this thesis paper:
«Research of the network efficiency in case of Narrow-Band Internet of Things (NB-IoT) usage in different spectrum scenarios»

**The relevance of the subject of thesis research.** With the development of the Internet of things (IoT), the number of connections to mobile networks of operators has increased significantly. As the IoT market grows, the use of innovative technologies such as NB-IoT narrowband wireless technology, which empowers mobile operators by "overlaying" this technology on the mobile network, becomes relevant. NB-IoT is an LTE-based radio access technology for fixed devices with low volume of data transfer.

In terms of advantages for low-power devices, NB-IoT technology is comparable only to 5G networks, the launch of which is slowed down due to the lack of free radio frequency spectrum and the high cost of telecommunications equipment. Therefore, at this stage, the NB-IoT technology integrated into 4G mobile networks becomes the most profitable option. For the deployment of this technology is sufficient 180 kHz of bandwidth, while for LTE technology it is necessary from 1.4 MHz to 20 MHz, and for 5G - at least 100 MHz.

The NB-IoT standard was specified by the 3GPP partner group in 2016 and is gaining popularity due to its cost-effectiveness to maintain and operate. However, there is a difficulty in the application of this technology, which consists in dynamically changing influences when using NB-IoT technology (external interference, collision), which degrade the quality of the mobile network.

There are three deployment scenarios for NB-IoT technology: stand-alone, guardband, and inband (spectrum sharing), which differ from each other in frequency distribution. The quality of the mobile communication network is highly dependent on the accuracy and reliability of determining the effectiveness of the chosen NB-IoT deployment scenario.

Existing methods do not allow to correctly calculate the efficiency of the network and determine the most optimal scenario for deploying NB-IoT technology on functioning 4G mobile networks, since they focus on a limited number of criteria, namely, the available frequency resource (bandwidth, frequency range).

At the same time, the choice of an effective scenario for deploying an NB-IoT network based on a 4G mobile communication network when providing Internet of Things services is very important, since it has a significant impact on:

- key performance indicators of the network;
- network quality indicators (QoE) and services provided;
- the number of potential subscribers of the IoT service;
- the cost of building or improving an IoT network (TCO).

Therefore, the issue of determining the effectiveness of NB-IoT scenarios should be solved comprehensively, and the effectiveness assessment should be carried out using a group of several most important parameters.

Mobile operators need to understand in advance which of the NB-IoT scenarios will be the most efficient and therefore preferable to deploy on an existing 4G mobile network, as well as help to achieve the best balance between the main economic and technical indicators of network performance. It has been proven that there is a necessity to develop an integrated methodological approach to assessing the performance of a 4G mobile communication network for the provision of NB-IoT services under various deployment scenarios in the frequency spectrum (stand-alone, guardband and inband).

The **target of the thesis research** is to develop a method for evaluating the effectiveness of the 4G (LTE Advanced) mobile radio access network for various scenarios of using narrowband channels of NB-IoT technology in the provision of Internet of Things services (stand-alone, with use of the guard-band and within the in-band) in the interests of developing technical strategies of mobile operators depending on the available radio frequency spectrum, performance and the bandwidth of the Internet of Things network.

To achieve the target of research, it is necessary to solve a set of theoretical, **research and practical problems**, namely:

- explore the features of the application of NB-IoT technology and the shortcomings of existing methods and approaches to assessing its effectiveness in the provision of Internet of Things services;
- identify technical factors affecting the efficiency of the use of radio network resources, as well as to determine and justify the choice of parameters (indicators) of the 4G (LTE Advanced) radio access network with NB-IoT technology that affect the efficiency of radio resource distribution management depending on the choice of the scenario for the use of NB-IoT frequency channels;
- develop evaluation criteria and a model for evaluating the efficiency of using network resources of the 4G radio access network (LTE Advanced) when using narrow-band channels of NB-IoT technology, with allowance for technical factors that affect the network efficiency;
- develop a multi-criteria method that is necessary for a comprehensive assessment of the effectiveness of the functioning of mobile networks, depending on the selected NB-IoT scenario;
- simulation of the functioning of the NB-IoT network, taking into account the main technical indicators of the radio access network proposed for use;
- to develop, based on the results of research, the mechanisms for implementing in practice the technological strategy of mobile network operators to select the scenario

for the use of NB-IoT frequency channels in the provision of Internet of Things services in the construction and operation of a radio access network;

- to test and endorse the results of the conducted research.

**The object of study.** Narrowband NB-IoT technology integrated into 4G mobile networks.

**Subject of study.** Efficiency of using the resources of the 4G mobile radio access network for various scenarios for the use of NB-IoT frequency channels in the provision of Internet of things services.

**Research methods.** The thesis research involves theoretical and experimental research methods. Theoretical studies involve the use of modern modeling methods in professional software environments, incl. Forsk Atol v.3.2.2. Experimental studies were carried out using the laws and patterns of radio signal propagation.

**Scientific novelty** of the thesis research:

1. A multi-criteria method for a comprehensive assessment of the functioning effectiveness of a 4G mobile communication network for the provision of NB-IoT services has been developed for various deployment scenarios in the frequency spectrum (stand-alone, in the guard-band, in-band).

2. Experimentally confirmed results have been obtained, which proving the dependence of the network indicators and parameters proposed for use on the NB-IoT technology deployment scenario.

3. A comparative assessment of NB-IoT network deployment scenarios based on the selected performance indicators was carried out, as a result of which it was revealed that the network operation efficiency when deploying NB-IoT technology in the guard-band interval is 11.84% and in the stand-alone mode by 6.58% higher than within using in-band option.

4. Based on a set of experimental studies and simulation results, mechanisms have been developed for implementing the technological strategy of mobile network operators in practice to select the scenario for using NB-IoT frequency channels in the provision of Internet of Things services in the construction and operation of a radio access network.

5. A patent of the Republic of Kazakhstan was obtained: "Method for determining the effectiveness of the application of NB-IOT technology on the 4G mobile communication network" No. 6322 dated 08/13/2021.

**Scientific provisions submitted for defense:**

- The declared method for calculating the effectiveness of the application of NB-IoT technology on 4G mobile communication networks using the calculated efficiency coefficient makes it possible to increase the reliability and accuracy of determining and choosing the optimal scenario for deploying NB-IoT, on condition of the quality of the mobile communications.

- According to the results of comprehensive studies with using the proposed method for calculating the efficiency coefficient, it was revealed that the efficiency of the network when deploying NB-IoT technology on 4G networks in the suburban area at frequencies

of 800 MHz: in guard-band interval by 11.54% and in the stand-alone by 6.58% higher than with using the in-band option.

- Mechanisms for implementing in practice the technical strategy of mobile operators to launch narrow-band IoT technology, depending on the available radio frequency spectrum, the planned load and bandwidth of the Internet of things are presented.

**The reliability and practical applicability** of the obtained results are confirmed by the implementation certificates received for the results of the thesis work from the telecommunications company "Huawei Technologies Kazakhstan" LLP (execute certificate dated 12/28/2019) and the Almaty branch of "Kar-Tel" LLP with the Beeline trademark (execute certificate dated 05.04 .2021). It is noted that the practical application of a multi-criteria methodological approach shall allow mobile operators and IoT service providers to optimize the process of implementing NB-IoT technology, reducing the potential time to launch the service.

The paper presents the results of experimental studies which were carried out complexly and duplicated by calculations by simulation model in the Forsk Atol software environment, with high measurement convergence.

**Approbation of the thesis results.** The results of the study were reported at the XI International Scientific and Technical Conference "Energy, Infocommunication Technologies and Higher Education", dedicated to the 45th anniversary of the formation of the leading university in the field of energy and telecommunications, as well as at the International Conference ICISCT 2020. All presentations are by the subject of the thesis.

**Publications.** On the subject of the thesis, 9 scientific articles and reports are presented, including: 5 scientific articles in domestic publications from the recommended by COXON list; 2 scientific reports in collections at international scientific and technical conferences, including those with a face-to-face presentation; 2 scientific articles indexed in the Scopus database, including 1 article (Article) in the "International Journal of Communication Networks and Information Security" journal with a percentile at the time of publication of 51% in the section "Computer Science: Computer Networks and Communications", and "Indonesian Journal of Electrical Engineering and Computer Science" with a 42% percentile at the time of publication into the section "Engineering: Electrical and Electronic Engineering".

The results of the research activities were recorded in the Patent of the Kazakhstan Republic for a utility model on the subject "Method for determining the effectiveness of the application of NB-IOT technology on a 4G mobile communication network".

**Personal contribution of the author.** Review, analysis of literature and patent search on the thesis research subject; implementation of simulation using professional software Forsk Atol v3.3.2; development of the content and plan of experimental research on a test cluster of a 4G network; preparation and conduct of experiments; processing and comparison of research results; publications in scientific journals and patent preparation; approbation of the results of a thesis. The scientific direction of work and research is determined with the participation of the supervisor and foreign consultants.

**The volume and structure of the thesis.** The dissertation work was completed by the author in accordance with the current requirements for design, structure, and content. The work consists of 3 main sections, list of symbols, introduction, conclusion, list of references and applications.

**The first chapter** provides an overview of how to measure the performance of 4G mobile networks and IoT technologies. A review of the literature on existing approaches and assessment methods is given. The rationale for the relevance and necessity of developing a new scientific and methodological approach for evaluating the effectiveness of mobile networks using various NB-IoT scenarios is presented.

**The second chapter** is devoted to the development of the model and criteria for evaluating the effectiveness of networks. The main indicators and factor groups are presented, the main provisions and methods involved in the calculation model are disclosed.

**The third chapter** contains a description of the developed multi-criteria method of complex assessment. An analysis of the results of experimental studies is presented. A comparative evaluation of the effectiveness of three NB-IoT scenarios was carried out. Mechanisms for implementing NB-IoT technology in practice have been developed.

Brief conclusions at the end of each section are given.

**The conclusion** summarized the results of experimental studies and the main conclusions of the thesis work.

**The appendices** summarized the results of the application of the method of expert assessments and the developed method of multi-criteria evaluation, measurement of network parameters in the 900 MHz range, acts of implementation from manufacturing enterprises, a copy of the patent.