Розроблено архітектуру інтегрованої мережі мобільного доступу п'ятого покоління на основі адаптації технології LTE до завдань управління людино-машинними комплексами. Модифікована структура фрейму LTE, в якій виділено логічний канал передачі даних телеметрії зі зменшенням затримки. Запропоноване рішення розширює функціональні можливості управління мобільними абонентами і безпілотними технічними засобами в режимі реального часу

Ключові слова: зв'язок п'ятого покоління, мобільний доступ, інтегрована мережа, людино-машинна система, технологія LTE, режим реального часу

Разработана архитектура интегрированной сети мобильного доступа пятого поколения на основе адаптации технологии LTE к задачам управления человеко-машинными комплексами. Модифицирована структура фрейма LTE, в которой выделен логический канал передачи данных телеметрии с уменьшением задержки. Предложенное решение расширяет функциональные возможности управления мобильными абонентами и беспилотными техническими средствами в режиме реального времени

Ключевые слова: связь пятого поколения, мобильный доступ, интегрированная сеть, человеко-машинная система, технология LTE, режим реального времени

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DEVELOPING THE ARCHITECTURE OF INTEGRATED 5G MOBILE NETWORK BASED ON THE ADAPTATION OF LTE TECHNOLOGY

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1. Introduction

According to the ITU concept, it is assumed that the next generation networks (NGN) will integrate most services based on Internet Protocol IP [1]. In particular, the fourth generation (4G) mobile communication networks provide for transmission of all types of multimedia traffic via IP by encapsulating data according to the TCP/IP stack [2, 3]. The IP multiple-service platform IP Multimedia Subsystem (IMS) based on the IP protocol is a certain trade-off between the existing network infrastructure and new requirements to service quality [4]. These new requirements arise because of the widespread use of microprocessor-based devices, both stationary and mobile, combined in a mobile access network. Solution of such tasks is considered within the framework of the concept of integrated mobile network 5GIN (5G mobile Integrated Network). The 5GIN structure includes separate segments of traditional telephone networks as well as specialized inter-machine interaction systems (M2M), sensor networks, structural components of the so-called "Internet of things", etc. [5, 6].

Managed sensor components of an integrated mobile access network usually have a wide range of various technical requirements. These requirements specify average data flow rate, delay time limitation, size of the packet data segments, the packet transmission frequency, and allowable fluctuations of these parameters. The 4G standard technologies require the use of modern highly efficient digital coding methods based on orthogonal frequency division multiplexing (OFDM).

The potential capabilities of the OFDM method and its implementation in 4G will make it possible to solve a wider range of tasks than envisaged in basic services such as Triple Play (transmission of voice, file messages, streaming video). But on the other hand, the standards and commercial technologies of 4G based on OFDM cannot satisfy to a sufficient degree the variety of requirements to 5GIN networks and, first of all, support for real-time applications. In this regard, the topical line of studies in the field of networking technologies is further modification of the LTE technology and development of integrated fifth-generation mobile access systems on this basis.

2. Literature review and problem statement

The standards of the fourth-generation networks are based on the LTE-A and WiMax-2 list of recommendations [2, 3]. The experience of deploying 4G networks in various countries (for example, in England, Germany, Poland, etc.), indicates that for the European region, including Ukraine, the most promising is introduction of a technology based on LTE and LTE-A standards [7]. The integrated 5GIN feature is that not only people but also high-speed electronic devices are the elements of interaction in such a network. These devices are controlled by one or more centralized processors within the integrated mobile access network. A typical example of a 5GIN network can be an automated distributed system designed to manage traffic safety at complicated metropolis traffic crossroads. In telephone networks, the so-called Two Way Delay (TWD) is an objective criterion of dynamism. Cyclic delay, apart from the objective component of TWD, also depends on subjective factors (the speed of the interlocutors' reaction and the length of the messages which they exchange with). Telephone networks based on circuit switching (Time Division Multiplexing (TDM)) have a minimum value of TWD, almost equal to the time of electromagnetic wave propagation through physical channels to both ends. The standardized value of one way delay (OWD) of voice transmission in modern digital telephone networks should not exceed 100 ms [8] with TWD≤200 ms. This requirement of limitation for TWD can be fulfilled for almost any two subscribers of a modern public switched telephone network worldwide (perhaps with rare exceptions).

The problem of controlling delay of voice transmission is one of the most complicated problems in the 4G networks with expansion of their geographical scale. To date, one of the best solutions in this regard is the Verizon Mobile (USA) network. This net is covering the entire territory of the United States and provides One Way Delay (OWD) of voice within 50 ms [9].

At the moment, it is unknown which 4G systems could function globally without the use of traditional TDM transport channels at long distances. Analysis of integration of the LTE networks across the USA by Verizon Wireless Company has shown that it is technically possible to create global 4G systems with OWD not more than 150 ms and TWD under 300 ms [10]. In the automatic control theory, a fact is known that the time delays in the feedback circuit of the control loop negatively affect quality of the object control [11]. In particular, growth of feedback delay in distributed systems reduces the system's speed and leads to appearance of spurious auto-oscillations which worsen accuracy of maintaining the specified parameters.

In prospective heterogeneous mobile access networks, the elements of which are not only people but also a variety of mobile technical devices, increase in the cyclic delay in the control loop can mean loss of controllability of individual devices. This leads to a rise of the risk of emergencies and limitation of the maximum permissible speed of object movement (for example, manned or unmanned vehicles).

In turn, the required control accuracy of mobile objects essentially depends on the rate of change of their parameters in time and space. For these reasons, the permissible cyclic delay in the mobile object control loop is one of the most important characteristics of dynamism of this particular object in its interaction with other objects of the integrated network environment.

The present-day standards and mobile communication systems of the fourth generation limit time delays in signal transmission at a level of 10 ms one way. This provides natural comfort from the point of view of speech perception when interacting in a dialogue mode between two persons. However, such delay limits are not sufficient for transmission of digital telemetry data and efficient interaction of present-day high-speed mobile devices in real time. On the other hand, the known specialized mobile communication systems of technical devices are, as a rule, local and not integrated into the telephone network via the mobile interface [12].

As noted in [13], packet delay is one of the key indicators of functioning of telecommunication systems. From this point of view, an important trend in LTE evolution is reduction of delay in the radio channel. Work [14] stresses necessity of creation of a new physical layer of the LTE technology and improved procedures for processing data at the MAC-level and network architecture for adaptation to the requirements of a broadband mobile access of a variety of technical devices in the Internet of Things concept. Authors of work [15] believe that the fundamental solution for the 5G mobile access networks consists in a combination of the existing 4G work infrastructure with development of new LTE capabilities in the standard frequency bands with regard to the requirements of technical devices.

For the first time, improvement of the LTE technology toward the packet delay reduction was undertaken in 3GPP R14 recommendations in 2017. In particular, the principle of access in the uplink of a physical LTE channel within 1 ms was formulated. Further activities in this direction are focused on the 3GPP R15 recommendations which are planned for 2018. Attention is focused on the use of smaller temporary fragments of the LTE frame (subframes, time slots and individual OFDM symbols) [16]. The basic idea of implementing such an approach consists in individual control of separate symbols by introducing a new uplink channel in the main band [17].

Analysis of the works published in recent years makes it possible to conclude that the unsolved task in creation of integrated fifth-generation mobile access systems is reduction of the packet transmission time in a radio channel to a level of 1 ms or less to connect high-speed sensor devices.

3. The aim and objectives of the study

The aim of present work was to develop architecture of an LTE-based integrated mobile access network of the fifth generation for real-time interaction of mobile subscribers and controlled objects.

To achieve this goal, the following tasks were accomplished:

– analysis of the features of application of a standardized LTE technology in real-time tasks in terms of temporary structuring of the LTE frame and the potentiality of reducing the time delay;

– modification of the LTE frame structure for operation in a special mode (ad hoc mode) in which the packet transmission delay is reduced by a factor of 10 compared to the standard mode;

– development of a method for synchronous multiplexing of real-time telemetry data and asynchronous multiplexing of packet data.

4. Functioning features of the LTE technology in real-time tasks

Distributed systems with the elements interacting in real time are characterized by such important indicator as cyclic delay of an abstract “server” response to an abstract “client”. For example, if during a telephone conversation one subscriber (“client”) asked another subscriber (“server”) a question, the time between the end of the question and the end of the answer received is cyclic delay; denote this delay by CTD (Cyclic Time Delay). The value of CTD depends on many factors including the delay of signal transmission through the communication channels, duration of the transmitted messages in the forward and backward directions as well as the time of server response to the client’s request.

It is quite obvious that an increase in CTD leads to a slowdown in the process of interaction between the network objects and, in general, to a decrease in dynamism of the “client-server” system (in the broad sense of the term “dynamism”). From the point of view of technical requirements to 5GIN networks, the LTE technology, on the one hand, is a promising 4G platform that can be improved and adapted to the requirements of the 5GIN networks. But on the other hand, the LTE technology has certain limitations as to the delay of message transmission because of a fixed duration of the LTE frame and frequency of transmission of these frames. The cyclic delay in LTE-based mobile access networks may appear unacceptable for connecting high-speed control objects within integrated 5GIN network.

Let us consider some properties of the LTE technology that are topical from the point of view of its possible adaptation to the technical requirements of mobile 5GIN networks. As is known, the base station (eNB) of the LTE access radio network cyclically generates 5 or 10 ms duration downlink (DL) half-frames depending on the duplex mode (time TDD or frequency FDD, respectively). The frequency of half-frame generation is fixed regardless the TDD or FDD mode and is equal to 100 Hz. The uplink half-frame is analyzed by all active UE cell devices, Fig. 1.

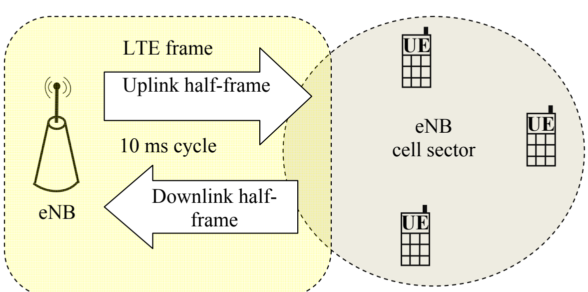


Fig. 1. General functional diagram of the LTE access network

Each UE device receives half-frames directly addressed to it. The half-frame contains the entire set of subcarriers of discrete frequencies in the given range with a sampling increment of 15 kHz. For example, 300 subcarriers are used in a 5 MHz band. The active cell devices jointly generate an uplink (UL) half-frame addressed to the base eNB station receiver. However, each UE device uses just a set of subcarriers assigned to it (for example, 12 discrete harmonics of a total of 300).

Fig. 2 shows the half-frame structure for a 3 MHz band in a FDD mode. The uplink and downlink half-frames have a time-frequency structure in a form of grid (LTE grid). The LTE half-frame grid is divided into 10 sub-frames of 1 ms duration each and this division is displayed in the horizontal grid plan. In the vertical plane, the LTE half-frame grid is divided into 15 frequency resource blocks with 12 subcarriers in each.

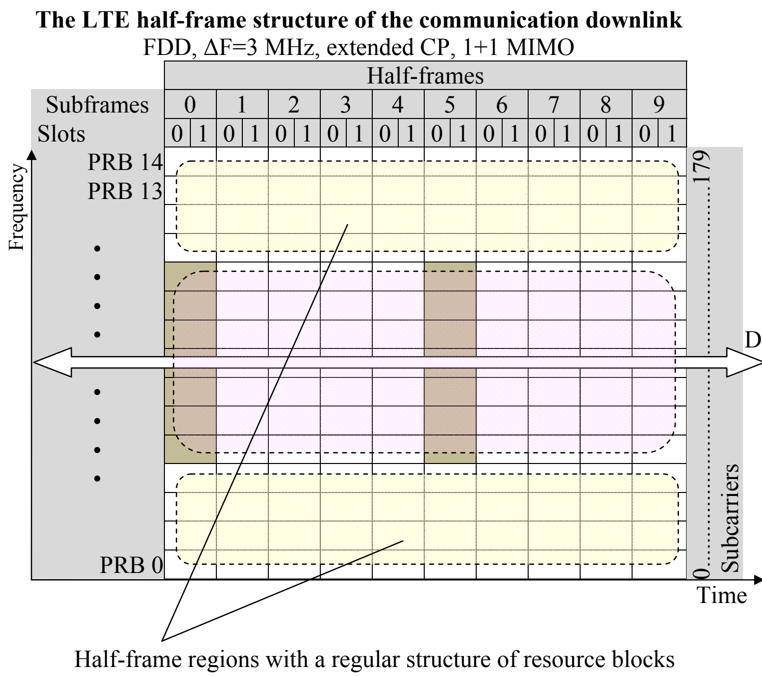


Fig. 2. General structure of the LTE downlink half-frame

As shown in Fig. 3, subframes and frequency resource blocks are combined into time-frequency resource blocks. Each subframe is formed by two time slots of 0.5 ms duration; one slot combines 6 or 7 elementary structural units called OFDM symbols. One OFDM symbol has duration of 0.0833 ms or 0.0714 ms depending on the chosen value of the cyclic prefix, CP (extended or normal, respectively).

At the logical level, the OFDM symbol is a complex sample of the modulated signal mathematically formed as a sum of Fourier series from all subcarrier harmonics. The mathematical concept of the “complex sum of Fourier series” is realized on the physical level by the method of I/Q-modulation, that is, by superimposing two separately received signals (the sum of all cosine components as a function of *I* and the sum of the sine components as functions of *Q*).

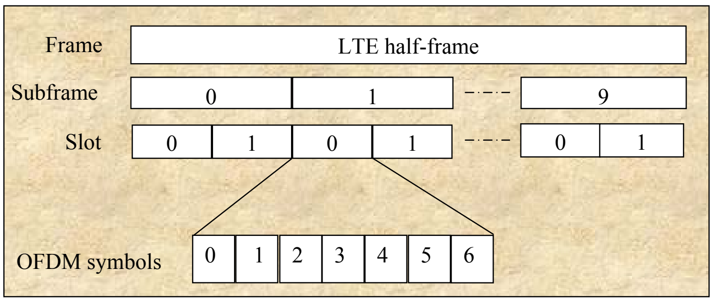
The period of repetition of elementary information units within the LTE frame (i. e. OFDM symbols) is determined by the fixed duration of one time slot (0.5 ms) and the number of OFDM symbols in a single time slot (6 or 7). Maximum duration of one OFDM symbol is

$$\Delta t_{OFDM} = \frac{0.5}{6}\,\text{ms} \approx 0.0833\ \text{ms}.$$

Thus, the minimum repetition frequency of OFDM symbols in an LTE radio channel is

$$f_{OFDM} = \frac{1}{\Delta t_{OFDM}} = \frac{6}{0.5\,\text{ms}} = 12\,\text{KHz},$$

which is 120 times higher than the repetition frequency of the LTE frames. Accordingly, the delay in transferring information by the OFDM symbol is 120 times less than the LTE frame transfer delay. These parameters determine the potential for adaptation of the LTE technology to the requirements of 5GIN networks in the sense of improvement of their dynamic properties.



LTE frame=10 ms; FDD half-frame=10 ms;
FDD half-frame contains 10 sub-frames;
Sub-frame=1 ms, contains 2 slots;
Slot=0.5 ms, contains 6 or 7 OFDM symbols;
OFDM-symbol=0.5/6 (or 0.5/7) ms=0.0833 (or 0.0714) ms

Fig. 3. Time components of the uplink LTE half-frame

5. Modification of the LTE frame to reduce packet transmission delay

In contrast to the traditional telephony systems based on TDM channels, modern 4G mobile communication systems use a packet data transmission method. In particular, in the LTE radio channel, the data are transmitted by periodically circulating frames with a fixed frame duration of 10 ms (the frame circulation frequency of 100 Hz). Thus, voice transmission in the LTE networks is performed by samples of an audio signal of 10 ms duration which are usually subjected to compression and noise-proof encoding at a vocoder level. When sending voice packet messages over packet networks, additional delays of a different nature take place. Each LTE frame is a logical combination of two physical half-frames, i. e. a uplink half-frame formed by the base station and an downlink half-frame formed by all active mobile devices of a particular cell.

Taking into account the above, the main line of adaptation of the LTE technology to the requirements of the 5GIN integrated mobile access networks is transition from the LTE frame to smaller parts in a sensor segment of the integrated net.

For this purpose, the general resource of the LTE radio channel should be divided into two parts:

a) a regular channel for providing mobile communication with a standard set of 4G services;

b) a dedicated channel with a special set of services having an increased data transmission frequency and reduced transmission delays (designate such channel as “ad hoc channel”).

Given the structural features of the LTE frame, the process of adapting the LTE technology to the 5GIN tasks is expedient to be carried out sequentially in two stages. At the first stage of adaptation, the information transfer cycle is reduced by a factor of 10 due to the use of a sub-frame of 1 ms duration as an information unit of data transfer. This transfer is carried out in the dedicated logical ad hoc channel.

At the second stage of adaptation of the LTE technology to 5GIN tasks, the data transfer cycle is further reduced by a factor of 12 (by the use of separate OFDM symbols as protocol units of data transfer in the dedicated ad hoc channel).

Let us consider in more detail the first stage of adaptation of the LTE technology to the tasks of creation of an integrated mobile access network of the fifth generation (5GIN).

Modification of the LTE frame for adaptation to real-time data transmission tasks with minimization of delays is performed as follows. Let us divide into two components the frequency resource of the LTE frame which circulates in a radio channel with a frequency duplex and repetition period of 10 ms:

a) a regular part of the frame in which duration of the data transfer cycle is equal to duration of the LTE frame, i. e. 10 ms (this part is located in the center of the LTE grid with subcarrier frequencies close to the main DC carrier frequency, Fig. 2);

b) the allocated part of the frame in which duration Δt of the data transfer cycle is 10 times less than 10 ms (Δt=1 ms); This part of the frame is localized on the edges of the LTE frequency grid.

Let us make structuring of the allocated part of the time-frequency resource blocks of each LTE subframe into packet transport modules (PTM) as shown in Fig. 4.

The subframe in Fig. 4 is formed by fifteen frequency resource blocks of which eleven blocks are used in a regular mode of the LTE operation (with numbers “–3” to “+7” in the upper half of the half-frame). The remaining four resource blocks (with numbers “–1” to “–4” at the bottom of the half-frame) are used to construct a dedicated logical channel that operates in a special ad hoc mode.

In the regular mode of the LTE radio channel, all ten subframes (with numbers 0 to 9 across) form a single transport module of the downlink radio channel which has duration of 10 ms and repetition frequency of 100 Hz. In contrast to the regular mode of using LTE frames, the lower four frequency resource blocks in Fig. 4 are reorganized into ten separate packet transport modules (PTM) with numbers from 0 to 9. Each PTM module is generated, transmitted and received independently of other PTM modules with a frequency of 1000 Hz and repetition period of 1 ms.

Each PTM module contains mandatory service information to support synchronization of the base station transceivers and mobile terminal devices. When transmitting information over an ad hoc dedicated logical channel, the data transmission delay is one millisecond (i. e., 10 times less than in using regular mode of the LTE radio channel).

The relationships between the information capacity for the regular and dedicated parts of the LTE frame can be dynamically changed in accordance with the current network operating conditions. These conditions include the number of terminal devices in the telephone and sensor segment of the net, assigned frequency range for the base station, the traffic intensity in each of the two segments of the integrated network, etc.

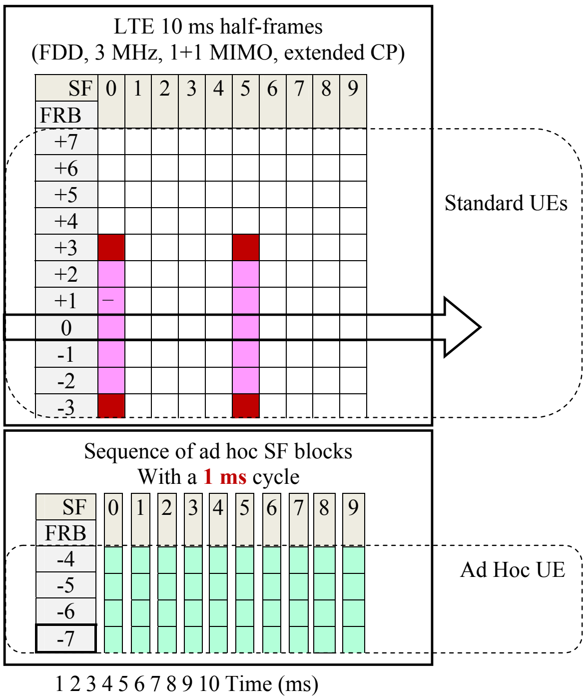


Fig. 4. The principle of combining the time-frequency resource blocks of the LTE subframe into packet transport modules

In the considered case of structuring the half-frame (Fig. 4), the number of frequency resource blocks that potentially can be used to construct a dedicated ad hoc logical channel is 1 to 8 of a total of 15 blocks. This is due to the fact that the central part of the half-frame with seven frequency resource blocks from "–3" to "+3" cannot be used because of the irregular structure of the individual subframes (Fig. 2).

6. Developing the architecture of the integrated mobile access system based on the modified LTE technology

In terms of the seven-layer model of the open system interaction (OSI), the 5GIN mobile access network must support the lower six layers from the physical layer to the representative layer inclusive. Let us define the following functional types of interaction between the network objects at the seventh (applied) OSI layer in the 5GIN network:

1) interactions of the P2P (People-to-People) type in the 4G Triple Play Segment in which two or more interlocutors conduct a real-time dialogue. The corresponding Triple Play client/server applications are implemented by operating systems of the terminal devices;

2) interactions of the M2M (Machine-to-Machine) type in the Sensor Network Segment in which two or more technical devices exchange with information in real time;

3) interactions of the P2M (People-to-Machine) type: information exchange between a man and a technical device through specialized or standard devices equipped with a mobile access interface.

The systems of the M2M type in which central device is the control central processor of the integrated network (CPIN), are distributed multi-channel automatic control systems; unlike M2M, designate such systems MCM (Machine-Control-Machine). Dynamic properties of the MCM systems are determined by the permissible rate of parameter change at which the specified control accuracy and stability of the system are ensured. These characteristics depend on the time lag of the objects and executing devices as well as on the delay of signals and feedback commands in the loop of the automated control system (i. e., on the cyclic delay CTD).

The cyclic delay in the control loop of the MSM system is calculated from the moment of measuring the parameters of the current object state (for example, coordinates, speed and acceleration of an unmanned vehicle at a traffic junction). Next, mobile telemetry data are transmitted to the control processor via the base station. These data are processed together with the data from other monitored objects. After that, decisions are made and control commands are sent to the monitored objects via a base mobile communication station. The moment the object receives the CPU command determines the end of the cyclic delay.

Let us consider functional features and structural elements of the 5GIN integrated access network based on the example of a network that supports 4G mobile communication and provides traffic safety, Fig. 5.

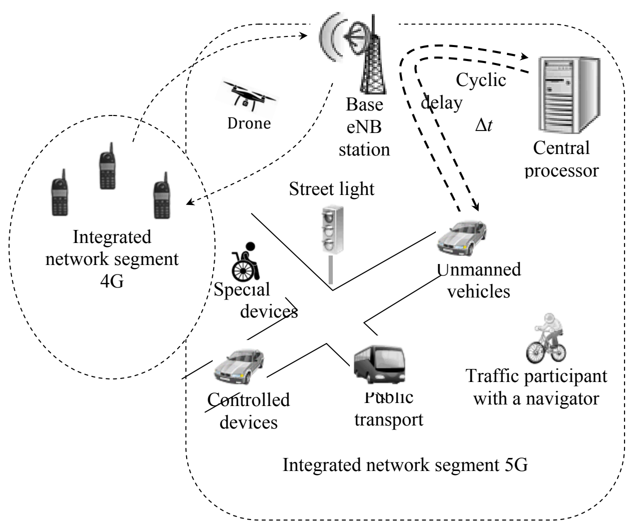


Fig. 5. Integrated 5GIN mobile access network for traffic safety control

This kind of network connects the traffic participants with the Central Processor of Integrated mobile Network (CPIN). The traffic participants may be pedestrians with mobile phones, disabled persons who move by means of remotely controlled vehicles, cyclists with mobile navigators, manned and unmanned vehicles, public transport. In terms of the "client-server" system, such terminal objects are "clients" in relation to the 5GIN mobile access net. The mobile access network together with its infrastructure acts as a "server" for the telecommunication services.

The core of this type of service is a base station with an evolved Node Base station (eNB) mobile network controller. At the same time, an additional service of an application level in the 5GIN mobile access network under consideration is control and management of traffic safety.

The clients of such service are traffic participants and the CPIN is the server of this service. The 5GIN integrated mobile access network shown in Fig. 5 contains two main segments: a 4G segment and a 5G segment. The 4G segment supports a standard set of Triple Play services. Designate this segment of the integrated network as a 4G Triple Play

Segment (4G-TPS). The 5G segment serves the sensor objects with an interface compatible with the modified radio channel of the LTE technology. Designate this segment as Sensor Network Segment (SNS). In this segment, a dedicated ad hoc logical channel is used in which real-time data are transmitted through the PTM packet transport modules. The delay is 1 ms (that is, ten times less than the regular mode of using the LTE radio channel in the segment of the 4G mobile telephone network).

Let us present the generalized architecture of the 5GIN integrated mobile access network based on the modified LTE technology as a merger of two main segments. The first segment is an ordinary 4G network and the second one is a segment of a sensor network with improved dynamic properties, Fig. 6.

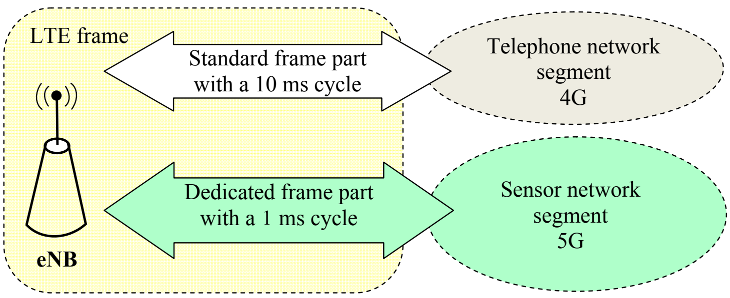


Fig. 6. General structure of the integrated 5GIN network based on the modified LTE technology

The sequence of the packet transport modules (PTM) in the dedicated logical channel will be used for synchronous and asynchronous multiplexing of various types of telemetry data for controlling sensor-equipped objects. The basic principles of this problem solution are described in [18].

Let us estimate the value of cyclic delay in the feedback signal transmission in the control loop which can take place when the sensor-equipped object of the integrated network (for example, an unmanned car) interacts with the CPIN central processor. Assume that all active sensor-equipped objects in the integrated 5GIN network, as well as the central processor of the network are synchronized with a frequency of transmission of the PTM modules (i. e., with a frequency of 1 KHz). In other words, in the 5GIN network under consideration, time can be conditionally considered discrete with a minimum quantum of 1 ms, Fig. 7. The cycle of feedback signal transmission in the control loop includes the following main stages:

1) measurement of the current state of the mobile object based on the sensor data. Denote with Δt_0 the time interval from the beginning of reading the sensor data to obtaining the evaluation results by the local controller.

2) transmission of the measurement results to the eNB base station via the uplink of the LTE radio channel with a delay Δt_{UP1};

3) processing information in the eNB node with a delay Δt_{C1};

4) transmission of information to the CPIN CPU via the downlink of the LTE radio channel with a delay Δt_{DW1};

5) processing information in the CPIN with a delay Δt_{C2};

6) transmission of information to the eNB base station via the uplink of the LTE radio channel with a delay Δt_{UP2};

7) processing of information in the eNB node with a delay Δt_{C3};

8) transmission of information to the object via the downlink of the LTE radio channel with a delay Δt_{DW2};

9) execution of a command at the object with a delay Δt_A.

Thus, the total cyclic delay ΔT in the feedback circuit of the object control loop is determined by the sum:

$$\Delta T = \Delta t_0 + \Delta t_{UP1} + \Delta t_{C1} + \Delta t_{DW1} + \\ + \Delta t_{C2} + \Delta t_{UP2} + \Delta t_{C3} + \Delta t_{DW2} + \Delta t_A. \quad (1)$$

Taking into account the time parameters of the diagram in Fig. 7, formula (1) takes the form

$$\Delta T = \left(\Delta t_0 + 7 + \Delta t_A\right) \text{ ms.} \quad (2)$$

It follows from formula (2) that the cyclic delay in the CTD control loop exceeds 7 cycles of information transfer delay in the LTE radio channel. If the standard LTE channel with a 10 ms transfer cycle is used, then the value of CTD will be more than 70 ms. In such a time, a car moving at a speed of 15 m/s (or 54 km/h) will move to a distance of about 1 meter which may be unacceptable from the point of view of accuracy of unmanned control of such car. Introduction of a real-time data channel with a transfer cycle of 1 ms reduces the error in estimating position of the car at this speed to a value of 0.1 meters.

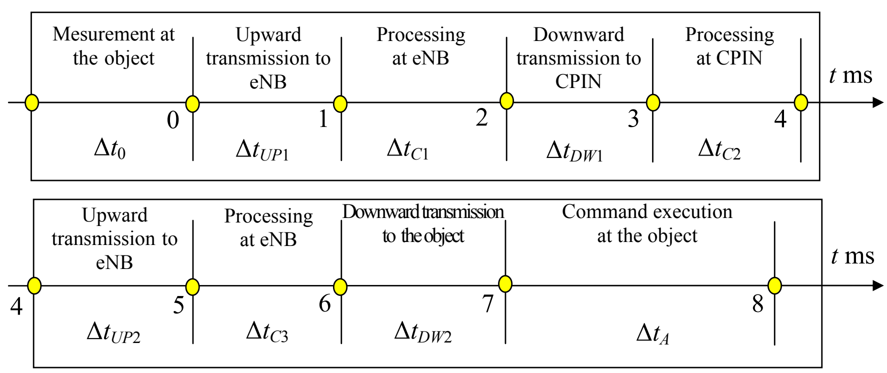


Fig. 7. Timing diagram of cyclic delay in the 5GIN network control loop

7. Discussing the results of development of an integrated mobile access system

The rapid growth of the variety of mobile devices connected to the Internet and the gradual transformation of the worldwide net into the so-called "Internet of Things" puts new serious challenges in integrating a large number of network subscribers with a wide range of technical requirements. Such tasks can be solved in various ways, one of which is creation of specialized networks operating under specific protocols independently of the public mobile access network. Studies in this direction are actively carried out in recent years. Advantages of specialized mobile access networks consist in their high speed and ability to solve non-standard tasks; their lack is a narrow field of application and complexity of interaction with public mobile telephone networks.

However, 4G mobile access technologies (first of all, LTE-A) do not yet fully use their potentials for integrating sensor-equipped objects in the concept of "Internet of Things". This aspect of the problem was considered in this study and the concept of building an integrated mobile access system based on the improved LTE technology on this basis was proposed. This work can be considered as one of the first steps in this direction. Further, in connection with the proposed concept, the following three main tasks arise for the practical implementation of an integrated fifth generation mobile access network:

1) development of an advanced protocol for processing LTE frames at the eNB base station controller which provides dynamic allocation of the time-frequency resource according to the principles indicated above;

2) development of a method and algorithm of multiplexing real-time data taking into account features of various sensor-equipped objects of the integrated network and meeting the requirement of guaranteed limitation of data transfer delay in the radio channel;

3) development of proposals for the further development of mobile communication standards based on the LTE technology taking into account a separate ad hoc logical channel and features of real-time data transmission via PTM packet transport modules.

Solution of these three tasks is the subject of further studies in a direction of creating an integrated fifth-generation mobile access networks based on modernization and improvement of the LTE technology.

8. Conclusions

1. It was shown that the physical layer of the LTE radio channel ensures a significant reduction of the delay of data transmission in radio channels of the fifth-generation integrated network. This will require development of an improved method for allocating resources at the MAC layer, as well as further development of the LTE-A standard.

2. A method for adapting the LTE radio channel by providing a separate logical channel operating in an ad hoc mode in which the data transmission delay is reduced by a factor of 10 compared to the typical mode was proposed. To implement the ad hoc channel, a method of packet transport modules was used. These modules periodically circulate in a 1 KHz radio channel at a 1 ms repetition period. Synchronous and asynchronous multiplexing of real-time data was carried out in the ad hoc channel.

3. Based on adaptation of the LTE technology, architecture of an integrated fifth-generation mobile access network was developed. This network combines a segment with a set of 4G services and a segment of a 5G sensor network with a special set of services.

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ONTOLOGICAL KNOWLEDGE BASES PRODUCTIVITY OPTIMIZATION THROUGH THE USE OF REASONER COMBINATION

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Проведено аналіз різонерів для роботи з онтологічними базами знань з метою збільшення швидкодії цих баз. Запропоновано варіант рішення, в якому комбінуються переваги «tableau»-based і «hypertableau»-based різонерів. Проведено аналіз можливості застосування такого рішення на сервері онтологічних баз знань «Virtuoso». В результаті дослідження був розроблений метод комбінації різонерів для оптимізації роботи онтологічних баз знань. В результаті застосування даного методу було отримано збільшення продуктивності роботи баз знань при роботі з різнотипними онтологіями

Ключові слова: комбінація різонерів, Jena, Virtuoso, hypertableau, tableau, HermiT, Pellet, FaCT++, ABox, TBox, RBox

Проведен анализ ризонеров для работы с онтологическими базами знаний с целью увеличения быстродействия этих баз. Предложен вариант решения, в котором комбинируются преимущества «tableau»-based и «hypertableau»-based ризонеров. Проведен анализ возможности применения такого решения на сервере онтологических баз знаний «Virtuoso». В результате исследования был разработан метод комбинации ризонеров для оптимизации работы онтологических баз знаний. В результате применения данного метода было получено увеличение производительности работы баз знаний при работе с разнотипными онтологиями

Ключевые слова: комбинация ризонеров, Jena, Virtuoso, hypertableau, tableau, HermiT, Pellet, FaCT++, ABox, TBox, RBox

1. Introduction

Currently, there is an increased use of the ontological model of domain description. This is the result of the versatility and flexibility of this model. Reasoners, which accounted for most of the time spent on processing ontologies, play an important role in it [1].

The standard solution for ontologies with unchanged structure of the classes and properties is a preliminary run of a reasoner during the load process of an ontology. This approach is effective on the condition that the result of the reasoning is cached. However, if you need to change the structure of an ontology, it becomes rather time-consuming, which is a problem for intelligent systems working in real time.

The possibility of combining different reasoning models depending on the type and structure of the ontology is being researched as an alternative solution to this problem.

The study has compared the characteristics of the most popular reasoners: FaCT++ Pellet, HermiT [1, 2]. The possibility of the combined use of these reasoners and ontological information store Virtuoso Server [3] has also been evaluated.

The particular attention has been paid to the description of optimization techniques based on the use of the HermiT reasoner. This particular reasoner is of great interest because unlike its analogues, such as FaCT++, Pellet, RacerPro, whose work is based on the standard tableau algorithm, it uses the hypertableau algorithm as an alternative. The application of the hypertableau algorithm is extremely useful and