IEEE 802.16: ANALYSIS OF PROBABILITY-TIME CHARACTERISTICS

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ABSTRACT
In this article we present probability-time characteristics of perspective wireless network WiMAX (IEEE 802.16 standard), which were derived by numerical analytic method of the load intensity balance and could be used for its building. Need for frame format adaptation of MAC protocol is noted from delay characteristics. Derived results allow efficiency characteristics estimating of perspective wireless network IEEE 802.16 and could be used for its building.

KEY WORDS
WiMAX, IEEE 802.16, Delay characteristics, Frame format, Balance of load intensity, Analysis

1. Introduction
Not long ago there has been published the standard of broadband mobile wireless access IEEE 802.16e [13], which together with the previous IEEE 802.16-2004 standard [12] (the commercial name - WiMAX) allows to realize integrated wireless networks for transfer of various types of the information (streams of a voice and data with time division, IP connections, a speech packet transmission through IP (VoIP) etc.) with the set quality of each service (QoS). Such networks will become fine alternative to existing wireless and cellular networks in the nearest future. The design of adequate analysis and optimization methods of operation for IEEE 802.16 becomes an actual problem, because there is necessity to increase efficiency and capability of this perspective wireless access protocol.

It is necessary to note, that in the available literature it is considered a little about the analysis of characteristics of WiMAX. Some present analytical models are given in [1-6]. The results of analytical researches, described in [1-6], are obtained without paying attention to many parameters, which characterize the principles of WiMAX protocol. The queues are supposed to be one-dimensional, infinite and without priorities, usually, streams of errors and negative acknowledgements, real input losses, propagation time and also heterogeneity of input traffic are not taken into account.

To eliminate the above-mentioned assumptions, for the problem solution of probability-time characteristics analysis of WiMAX-networks, in the given article the numerical analytic method of the balance of load intensity is developed. This method is described in details in [7], and was used for the efficiency analysis of multiservice mobile networks, and networks with fixed frame format like WiMAX in [8-11,15].

2. MAC layer of the IEEE 802.16 standard
The 802.16 MAC (Medium Access Control) describes a number of Convergence Sublayers which describe how wireline technologies such as Ethernet, ATM and IP are encapsulated on the air interface and how data is classified, etc.

A key feature of 802.16 is that it is a connection oriented technology. The subscriber station (SS) cannot transmit data until it has been allocated a channel by the Base Station (BS). This allows 802.16e to provide strong support for Quality of Service (QoS).
Subscriber stations can only interact with BS, passing on the uplink channel their requests (for example on the extraction or expansion of bandwidth) and data. The example of such a network construction and connection of BS and translator in PTP is shown on the fig. 1. By the uplink channel from the BS subscribers get control information and also the data they are intended. The data stream in the standard IEEE 802.16 - is a stream of packets. Data packets, which are formed on the MAC-layer, called the MAC PDU (MAC Protocol Data Unit, the data blocks of MAC-layer). Structure of MAC PDU data packets is shown on the fig. 2.

<table>
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<tr>
<th>Generic MAC header</th>
<th>Payload (optional)</th>
<th>CRC (optional)</th>
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Packet includes the MAC-header, the data field (payload), then may be follow a cyclic redundancy check (CRC). PDU header consists of 6 bytes and can be of two types - general and request header for allocation of bandwidth (Bandwidth Request – BR). If the packet contains a data field, then use a generic header that contains a connection identifier (CID), the type and header CRC, as well as information about the data field (e.g. packet length). In the case when the SS asks BS allocate or increase its bandwidth in the uplink, bandwidth request header (BR), which indicates CID and the size of the necessary bandwidth, is used. The data field after the request headers of the packet is absent.

Data transmission on the physical level is carried out by a continuous sequence of frames of fixed length. Each frame consists of two subframes – downlink subframe and uplink subframe. FDD – frequency division duplex and also TDD – time division duplex are provided by IEEE 802.16 standard. In case of FDD transmission away from SS and BS comes at the same time, but there is frequency spacing. Consecutive data translation at first from BS and then from SSs with the same frequencies is supposed in case of TDD. Uplink and downlink subframe ration in the one frame can be varied during operation depending on the required bandwidth for uplink and downlink channels. Superframe format in case of TDD is shown on fig. 3.

BS transmits list of packets profiles (list of packets parameters, including type of modulation, coding scheme, signal/noise relations value) in the form of special control messages – DCD/UCD descriptors not less than once a 10 seconds.

BS reserves time slots in uplink subframe for the transmission subscribers. The information about allocation of these slots is situated in UL-MAP messages. The basic principle of radio access in the standard is a DAMA – Demand Assigned Multiple Access. The standard provides two kinds of multiple access – free access and controlled access. In case of free access subscribers compete for opportunity to transmit their requests in special interval. So collisions are possible by reason of synchronous transmission of requests from different stations. Collision control mechanism is like “Backoff” mechanism in IEEE 8802.11 standard.

In this paper we pay more attention to controlled access WiMAX system. Base station poll subscribers about their needs in bandwidth resources. It means that all active SSs have own time-slot in the uplink subframe for their bandwidth requests.

Five networks modes are provided by IEEE 802.16 standard - WirelessMAN-SC, WirelessMAN-SCa, WirelessMAN-OFDM, WirelessMAN-OFDMA and WirelessHUMAN. WirelessMAN-SC is designed to work in the band of 10-66 GHz and is oriented to the backbone networks, operating in the line of sight mode. The remaining modes are designed for bands low than 11 GHz. WirelessMAN-SCa – “low-frequency” version of WirelessMAN-SC (with an expanded set of additional mechanisms). WirelessMAN-OFDM and WirelessMAN-OFDMA - new methods, based on the use OFDM modulation. WirelessHUMAN - mode adapted for unlicensed in the U.S. 5.6 GHz band, based on the same methods that are used in modes WirelessMAN-OFDM and WirelessMAN-OFDMA.

### 3. WiMAX protocol’s computational model

In this article characteristics of WIMAX system delay time in uplink channel are presented. They have been received for WirelessMAN-SCa mode with 25 MHz channel and with the speed of physical data stream equals 40 Mbits/s (QPSK modulation).

Now, let’s look at the system with point-multipoint topology (BS - SSs). The uplink and downlink subframe ration equals 1:1 (while determining uplink channel’s bandwidth, we didn’t take into account BS’s traffic). On fig. 4 WiMAX protocol model in space-time diagram that was used to count the characteristics of data packet delays is shown. Propagation time is less than the duration of one frame. Active mobile station (that is not registered for the first time) has the data packet for transmission. It inform BS about it with the help of bandwidth request in a selected interval in an uplink subframe.
The IEEE 802.16 standard frame is fixed in its size and its duration can be 0.5; 1 and 2 ms (in WirelessMAN-SCa mode). In a big network load, what is due to other subscribers, there can be a situation when BS doesn’t provide an interval to a subscriber needed for data transmission in the closest frame (it’s shown on fig. 4). In this case SS sends the second request and as an answer to it BS informs it (by UL-MAP message) about the starting moment when it can transmit its packet.

As an option, the standard provides confirmation sending of the base station and the second transmission of packet (ARQ - Automatic Repeat Request) in case of impossibility its decoding (fig. 4 doesn’t show this case, but it will be considered while numerical analyzing of characteristics). So, the packet delay time is determined from the moment when it appears for transmission till the end of its reception by the base station.

From the point of view of WiMAX system analysis, the most important efficiency characteristics are the time characteristic of subscribers’ data delivery, because this parameter reflects the network performance. In this paper the dependence of packet delay time (that are built from the intensity of input load) while changing the number of subscriber’s data packets in the uplink subframe J (with the little propagation time, less than the frame’s duration) with the changing of the bandwidth cost value needed to transmit one bandwidth request which is 6 bytes according to the standard, and also the dependence of packet delay time with the changing of bit errors probability are presented.

The detailed of mathematical description of problem statement and solution of probability-time characteristics analysis task with the help of numeric analytical method of the load intensity balance can be found in [7].

For the calculation of characteristics, the subscribers’ data packet size equals in our case 1024 bits (thereafter, the duration of 1 bit with a target speed of 40 Mbits/s (QPSK, channel width 25 MHz) is 0.025 µs) and the number of active subscribers was set equal to 128.

Calculation was made in MathCAD program.

Below, you can see numerical analysis of obtained results.

4. Numerical analysis

On fig.5 there are delay characteristics of packets transmitted from subscribers. These characteristics vary with input load intensity (normalized) while number of packets J varies too.

It is obvious that initial delay will increase with growth of the number of information time step (due to growth of WiMAX super-frame duration). Bandwidth will increase too because of the change of service/information time step ratio. In this case it assumes that there is no noise in the channel and bandwidth reaches due to increase of the frame overload probability with growth of input load and lack of slots for user data transmission.

Analyzing characteristics on fig.5 it could be noted that increase of input load intensity demands dynamic adaptation of the frame format and increasing of the number of the information time step. Dotted enveloping
curve on the plot is a characteristic of exactly that protocol with the frame dynamically optimizing to the load.

Three frame formats (0.5; 1; 2 ms) proposed in IEEE 802.16 standard, obviously, couldn’t be optimal for the whole load range. It means that WiMAX system works out not enough effectively and uses not all its own resources due to lack of the frame size adaptation for user’s load on MAC layer. Thus, the problem of characteristics optimization (solving for the optimum of the ratio between input load intensity and frame format) is still urgent.

Another way to increase WiMAX protocol bandwidth (and its efficiency also) is to decrease expenditure of access management. Value of bandwidth request as in standard [13] is 6 byte for each user’s station.

Fig.6 shows time delay dependence on input load intensity with changing of request bandwidth. In this case, for simplicity’s sake, it assumed that the time of the signal propagation is less then the frame duration and channel noises causing mistakes of data transmission are absent.

Plots confirm logic conclusion that decrease of expenditure for access management makes delay characteristics better at the cost of the decrease of initial time delay (frame size decrease) and increase of bandwidth (part of the user’s data in the frame is increasing). Numerical analysis shows decrease of the request bandwidth from 6 to 3 bytes depending on the number of time steps in the frames which are used for transmission of information packets. So, it improves bandwidth to 2-11%.

Hereinbefore characteristics of MAC protocol of WiMAX standard with fixed frame format were considered but it assumed that there is no noise in the channel and delay characteristics depends on frame size only (and thereafter lack of the information time steps causes frame overload). So it is idealized case. In reality, noises always take place in the radio channel and it causes errors. In analysis of time-probability characteristics method of intensity load balance [7] can take into account those errors thanks to the coefficient of mixed negative acknowledgement.

Fig.7 shows influence of errors to packet delay characteristics of IEEE 802.16 standard which were produced in conditions specified before. Analyzing these dependencies, increase of initial delay and decrease of bandwidth due to radio condition degradation could be noted. It is caused with increase of the number of mixed negative acknowledgements which in turn were caused with packet transmission errors. This increase affects on the duration of service cycle and therefore defines time delays. Degradation of delay indicators is noticeable even though time delay is quite litter. Obviously the increase of the time of the signal propagation causes considerable degradation of these characteristics.

5. Conclusions

Nowadays the special attention of communication statements and designers of the new equipment is compelled to systems of broadband access. Wireless networks based on WiMAX possess exclusive advantages on efficiency of expansion, cost, territory coverage, and also mobility.

Today the standard IEEE 802.16, which is underlaid of WiMAX, continues to develop and be improved, so the special urgency is got by the decision of problems in
increasing of efficiency of its functioning. In the standard there are already some possibilities giving a freedom of action to manufacturers at its application (for example, the standard reserves 256 types of control messages, it is used only 48 of them). However for essential increase of efficiency application of new operating commands it will not be enough. It’s necessary to make fundamental changes at the MAC-layer of the standard.

In this article we presented probability-time characteristics of protocol WiMAX with the fixed frame format, received by means of a numerically-analytical method of load intensity balance [7], displaying some possibilities for increase of the protocol efficiency. Time delay dependence on intensity of input load at change of the slots number which have been allocated for user's data, demonstrates necessity frame format dynamic adaptation in the course of load change. Similar dependence at change of control packages size, also shows possibility of channel capacity increase by minimization of this size (it’s possible when it used more effective methods of multiple access).

In article there has been also considered the influence of propagation time and other factors on protocol characteristics, it’s obvious that there are problems at the MAC-layer, requiring elimination.

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