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Study of data scheduling methods in the WiMAX mobile metropolitan wireless networks

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ABSTRACT

The paper discusses basic assumptions of the WiMAX Mobile system. It also presents and analyses the results of simulation tests run for selected data scheduling methods and subcarrier allocation. Based on the test results, the authors have prepared a comparative analysis of two popular data scheduling methods, i.e. WRR and PF, and their own method CDFQ which uses information about the current channel situation for the queuing processes and data allocation. The tests have been conducted with a simulator designed by the authors, based on work defined quality criteria.

KEYWORDS: MAN, scheduling, WiMAX

1. Introduction

Networks based on the WiMAX Mobile system *(Worldwide Interoperability for Microwave Access)*, described in detail by IEEE 802.16e and IEEE 802.16m standards, give their users braodband access to the services of the Internet [1]. Many years of experience show that networks based on WiMAX family standards ensure the delivery of high standard services to their users by providing support for the quality of service management mechanisms QoS and data transmission with advanced mechanisms of data stream classification. It is worth mentioning that orignially the WiMAX standard was designed to be used in areas of the highest demand for data transmission services requiring broadband access. It is true that recently the WiMAX network has been deployed mainly in areas where the cable Internet access is impossible or uneconomic - and the good example of it is Poland. Networks based on WiMAX Mobile standard are used for example in South Korea (called *WiBro*) and Amsterdam (called *Worldmax*) [1][2]. Scheduling mechanisms of quality of service management used in WiMAX networks are very similar to those which are now used in LTE and LTE-Advanced networks [5]. WiMAX and LTE standards show a lot of similarities when it comes to the structure of the lower layer protocol of the two systems. Some experts think that what supports the market application of WiMAX and LTE technologies are mostly business strategies, and the objective technological factors seem to be of secondary importance here [1][2][3][4][5].

Discrete event simulator of the WiMAX Mobile system, designed for the purposes of the research described in this paper, allows to perform a series of significant simulations, connected i.a. with research on the influence of data queuing methods used in BTS on different indexes of transmission quality. Particularly, the simulator makes it possible to run tests for 3 different standardised channel models described in recommendation ITU-R M.1225, i.e.: Pedestrian B (for v = 3 km/h), Vehicular A (for v = 60 km/h and 120 km/h) and 3 data scheduling methods: WRR *(Weighted Round Robin)*, PF *(Proportional Fairness)* and our own method, called further in the work - CDFQ *(Channel Dependent Fair Queuing)* [3][4][6].

2. Basic features of the WiMAX mobile system

The WiMAX version designed for mobile users, uses the Wireless MAN-OFDMA interface to carry out the basic multiple access method. A dynamic allocation of physical resources is done through a scheduling mechanism of a BTS, which assigns a certain subset of subcarriers grouped in so called subchannels to each terminal depending on its needs and in a way consistent with a standard [5][6][7][8]

In the MAC sublayer of the WiMAX Mobile we can distinguish three sublayers (fig. 1) [3][4][6]:

- convergence sublayer CS
- common-part sublayer CPS
- security sublayer SS

Sublayer CS is responsible for formatting so-called packet data units PDU coming from higher sublayers, their classification and transmission. Sublayer CPS performs the most crucial function of MAC sublayer. The layer consists of a core of the MAC sublayer (so-called MAC Core (fig. 1)) which is responsible for, i.a.: transmission and reception of protocol messages, management of AMC - adaptive modulation and coding profiles (which optimises transmission to and from each terminal by adapting its link's features and parameters depending on the current conditions of a radio channel), registration and connection initiation of the terminal with the network, band and service management, and many others [1][5][8]. The MAC sublayer of the WiMAX Mobile is where complex processes of data scheduling are implemented, which is the subject matter of this paper. Dynamic allocation of physical resources to particular terminals is done by a scheduling mechanism of a BTS, which assigns a certain subset of subcarriers to each mobile station in order to service it. It is necessary to emphasise the importance of so-called hybrid variation of the ARQ protocol *(Automatic Repeat-reQuest),*implemented in the MAC sublayer of the Mobile WiMAX, called HARQ, which generally serves to detect transmission and retransmission errors. HARQ uses not only error-detection codes but also error-correction codes and uses retransmission to improve the reception quality [10].

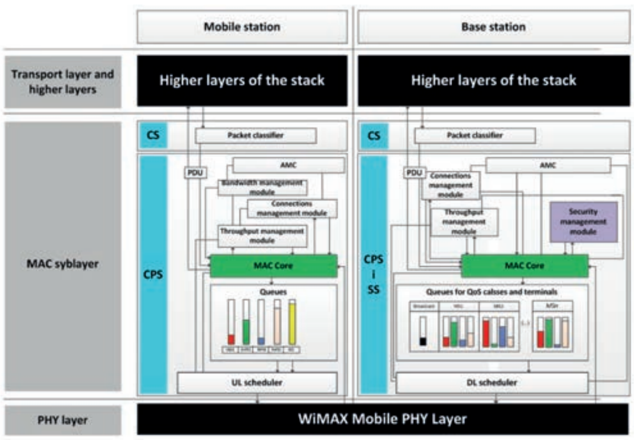

Fig. 1. A simplified layer model of WiMAX Mobile protocol [1, 2]

Then the compression module independently compresses each image according the the picture compression factor received from the analysis module. The compressed images are then passed to do the data transmission system (a modem) which implements their transmission by means of a selected telecommunications system.

3. Data scheduling methods used in the WiMAX mobile system

In order to support different services, WiMAX Mobile defines 5 categories of services, connected with different requirements of QoS *(Quality of Service)*. The procedure of data scheduling in WiMAX Mobile is a two-stage, complex process of handling data streams flowing from and to terminals. The first stage involves scheduling packets flowing from and to terminals. The second stage, on the other hand, involves servicing queues and allocation of physical resources for packet transmission to particular terminals [8][9]10]. The most popular, and at the same time, the easiest method of data scheduling is WRR method, which is the least complex method computationally and the easiest to implement. The basic version of the method does not support the QoS mechanisms [4][5][6][7] because each of the packets, which is part of the queue, is handled in an unalterable order, based on so-called carousel (rotary) mechanism of queue handling. In networks, where packets stored in queues are of different lengths (and in practice that happens most often) the duration of each round can vary over time. When we deal with aggregated data-stream, which includes packets of different types (which also means different lengths), the handling time for each packet in WRR method is variable over time and is difficult to determine. Another popular data scheduling method, which ensures a certain compromise between throughput and so-called fairness in handling packets coming from different users, used by some BST manufacturers of WiMAX Mobile and LTE systems, is the PF method [5]. In this method the servicing priority of a given logical stream[1] with a unique SFID is set based on the current throughput in relation to the throughput measured some time before, at not too distant points in time. Thanks to the dynamic throughput regulation, the PF method can adapt do the current network load and requirements of different services, in order to achieve a compromise between throughput and fairness. This method is often used by operators of commercial LTE networks [6]. The data scheduling method proposed by the authors of the paper called CDFQ, described in more detail in works [5], [6] and [7], belongs to the CDS group of methods*(Channel Dependent Scheduling)*which includes both the process of data stream scheduling and physical resource block allocation, according to the rules described in the standard. Data scheduling in CDFQ method

[1] WiMAX standard defines a notion of so-called logical link which is connected with a one-way packet stream belonging to a particular QoS category between protocol stations of MAC sublayer of a terminal and a base station. Such stream is identified by a Service Flow Identifier SFID.

starts with determining the value of the priority function $P_{nd(tn),m}$ [2] (where: n_d=1,2...,5 and is a QoS category index, and m=1,2...,M is an index of physical connection) at a certain moment t_n for each of the serviced logical links. WiMAX Mobile allows at most 5 logical links in each physical connection. Therefore, at a time point t_n a BST can not service more than 5M logical links, although the number is usually lower than that. In the CDFQ method, the logical streams which include packets belonging to the UGS category *(Unsolicited Grant Service)* are assigned the same number of subcarriers, which allows constant bit rate. The number of assigned subcarriers is updated every 5 ms, so that the system can respond appropriately to the changes of the channel characteristics and parameters. Once the procedure of determining the value of the function $P_{and(tn),m}$ is over, then starts the process of sorting physical links described by CID according to the values of the CINR parameter (*Carrier to Interface + Noise Ratio)* in descending order. The physical connection with the highest CINR value according to CDFQ method is assigned the most subcarriers, whereas the connection with the lowest CINR value the least. Such approach guarantees all terminals fairness of access to all resources, since it is the current quality of channel that decides about the scope of access of a particular terminal to the resources of the system.

4. Quality indexes defined for data scheduling methods

In order to compare the efficiency of the implemented data scheduling methods, we have identified three quality indexes listed below:

- total bit rate $\boldsymbol{R_S}$ of the system,
- packet error rate - PER,
- fairness ratio - FR (describing so-called scheduling fairness of packets of different users).

Bit rate $\boldsymbol{R_S}$ of the system can be determined according to the formula [8]:

$$R_S[bps] = T^{-1} \cdot \sum_{t_n \in T} \left(\sum_{k=1}^{K} \sum_{n=1}^{N_K} l_{rec(k,n)}(t_n) \right) \quad \textbf{(1)}$$

where:
$\boldsymbol{T}$ [s] – observation time,
$\boldsymbol{K}$ – number of users,
$\boldsymbol{N_K}$ – number of subcarriers assigned $\boldsymbol{k}$- to this terminal,
$\boldsymbol{l_{rec}}$ – length of received and decoded packets[3].

Packet error rate PER has been defined as a ratio of the number of received packets with detected errors to the total number of sent packets.

Fairness ratio FR used for the sake of this discussion is described by formula (2), where the numerator in the fraction represents the total length of packets of a user who received the most of them (***p*** user) less the sum of packet lengths of the user who received the fewest of them (***r*** user), in relation to the total length of sent packets.

$$FR = 1 - \left(\frac{\max_p \sum_{i=1}^{N_p} l_{pi} - \min_r \sum_{j=1}^{N_r} l_{rj}}{\max_p \sum_{i=1}^{N_p} l_{pi} + \min_r \sum_{j=1}^{N_r} l_{pj}} \right) \quad \textbf{(2)}$$

where:
$\boldsymbol{l_{pi}}$, $\boldsymbol{l_{rj}}$ – length of packets of a particular user ***p***-this and ***r***-that,
$\boldsymbol{N_p}$ – number of data packets sent by ***p***-this user,
$\boldsymbol{N_r}$ – number of data packets sent by ***r***-that user.

It is worth mentioning here that that value of the index FR defined in such a way is in the range between 0 and 1, and to consider the service as fair, the value should be close to 1.

5. Simulation results

The tests were conducted for 3 standardised models of channels, described in detail in recommendation ITU-R M.1225 and in the paper [3]. The simulation was run on a single cell of the WiMAX Mobile system, in which the number of active users varied in the range between 30 and 190. The experiment used different standardised models of channels described in the paper [7] and in the Table 1-3.

Table 1. Parameters of a standardised model of channel ITU-R M.1225 Pedestrian B (v=3 km/h) [own study]

Path	Delay along the path [µs]	Relative propagation attenuation [dB]
1	0.00	0.0
2	0.20	0.9
3	0.80	4.9
4	1.20	8.0
5	2.30	7.8
6	3.70	23.9

Table 2. Parameters of a standardised model of channel ITU-R M.1225 Vehicular A (v=60 km/h) [own study]

Path	Delay along the path [µs]	Relative propagation attenuation [dB]
1	0.00	0,0
2	0.31	1,0
3	0.71	9,0
4	1.09	10,0
5	1.73	15,0
6	2.51	20,0

Table 3. Parameters of a standardised model of channel ITU-R M.1225 Vehicular A (v=120 km/h) [own study]

Path	Delay along the path [µs]	Relative propagation attenuation [dB]
1	0.00	0,0
2	0.31	1,0
3	0.71	9,0
4	1.09	10,0
5	1.73	15,0
6	10,00	20,0

[2] Each logical link has a unique ID called SFID. On the other hand, each physical connection (the number of which can be at most $\boldsymbol{M}$), is described by a unique ID called - CID *(Circuit IDentifier)*.

[3] When running simulations it was assumed that a packet is rejected when it can not be correctly reconstructed in the receiver [7].

Table 4. Test scenarios [own study]

	Test scenario I	Test scenario II	Test scenario III
$P_{Ped.B\_3\ km/h}$	1	1/3	0,1
$P_{Veh.A\_60\ km/h}$	0	1/3	0,2
$P_{Veh.A\_120\ km/h}$	0	1/3	0,7

where:

$P_{Ped.B\_3\ km/h}$ – probability that Pedestrian B, v=3 km/h; model of channel will be assigned to a given terminal in the simulation

$P_{Veh.A\_60\ km/h}$ – probability that Vehicular A, v=60 km/h; model of channel will be assigned to a given terminal in the simulation

$P_{Veh.A\_120\ km/h}$ – probability that Vehicular A, v=120 km/h; model of channel will be assigned to a given terminal in the simulation

Test scenario I (Table 4) reflected a situation where all terminals in a simulation cell WiMAX are moving at the same speed v=3 km/h and each terminal is assigned one and only one standardised model of channel, i.e. Pedestrian B (tab. 1). On the other hand, in the test scenarios II and III the speed of the moving terminals in a cell is not constant (standardised models of channels were assigned to particular terminals according to distribution of probabilities described in Table 4).

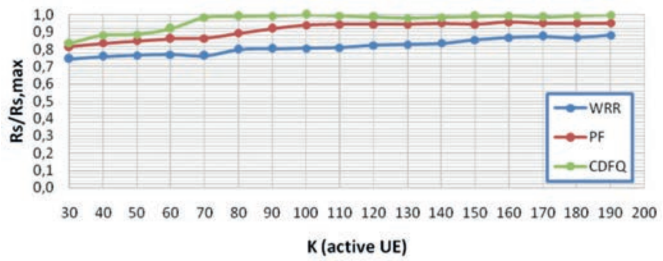

Fig. 2. Dependence of standardised total throughput in a cell on the number of active terminals (test scenario: I) [own study]

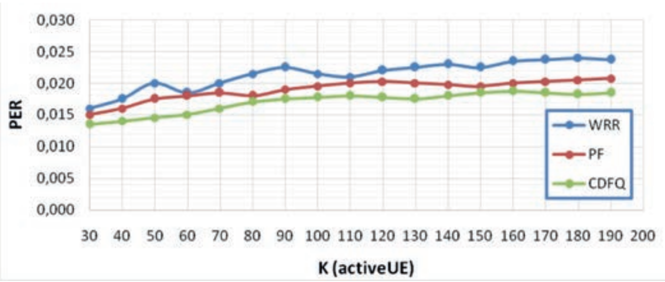

Fig. 3. Dependence of packet error ratio on the number of active terminals (test scenario: I) [own study]

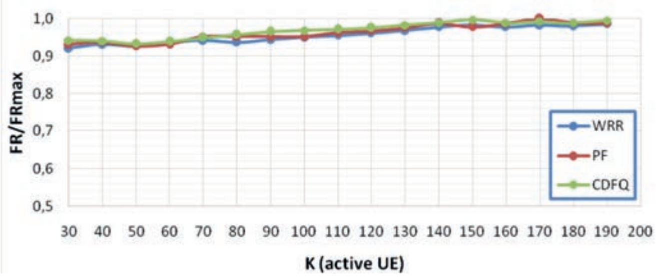

Fig. 4. Dependence of standardised fairness ratio on the number of active terminals (test scenario: I) [own study]

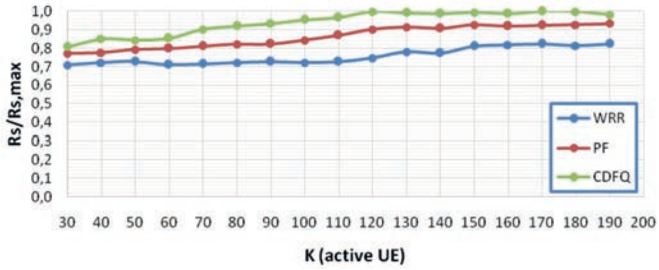

Fig. 5. Dependence of standardised total throughput in a cell on the number of active terminals (test scenario: II) [own study]

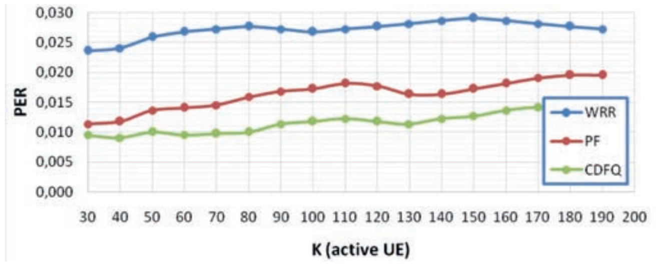

Fig. 6. Dependence of packet error ratio on the number of active terminals (test scenario: II) [own study]

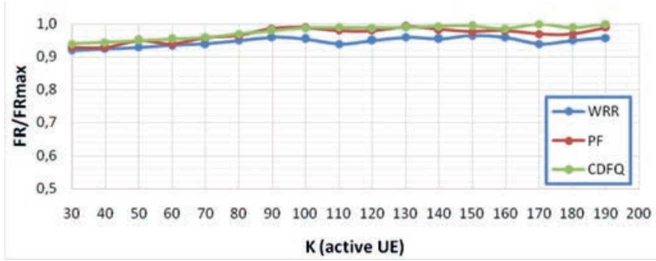

Fig. 7. Dependence of standardised fairness ratio on the number of active terminals (test scenario: II) [own study]

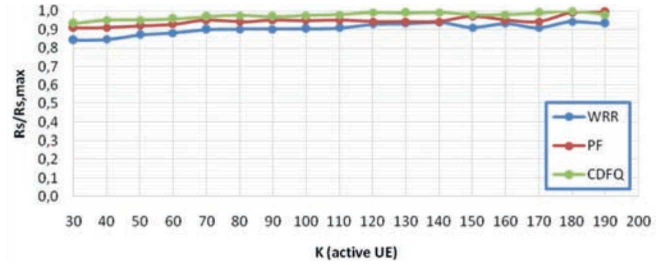

Fig. 8. Dependence of standardised total throughput in a cell on the number of active terminals (test scenario: III) [own study]

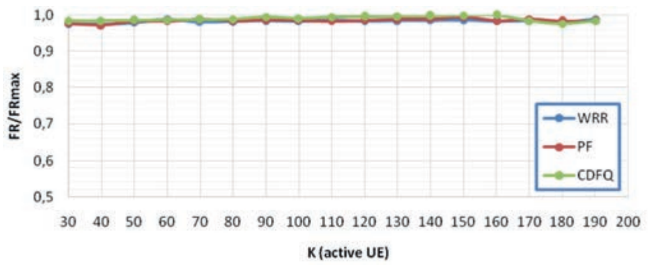

Fig. 9. Dependence of packet error ratio on the number of active terminals (test scenario: III) [own study]

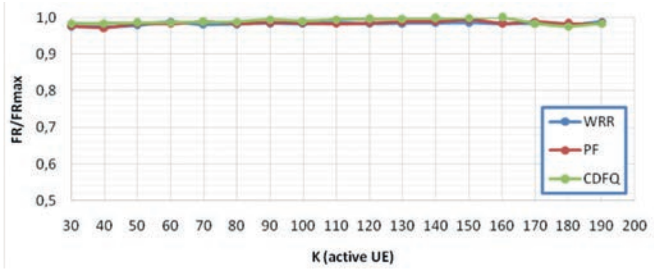

Fig. 10. Dependence of standardised fairness ratio on the number of active terminals (test scenario: III) [own study]

The results of the simulation tests have shown that the method CDFQ, proposed by the authors of the paper, proves to be most efficient in a mixed environment, where none of the standardized models of channel is visibly dominant. In such cases the quality indexes assumed in the tests confirm the benefits coming from applying the proposed method for data scheduling. Simulation tests have also shown that in simulated operating conditions and with the assumed transmission parameters, applying the proposed method can cause in certain conditions a double-digit increase of the total throughput in a cell (in relation to WRR and PF methods), while the value of PER decreases by several percent. [7] In situations when all terminals are moving at the constant speed of 3 km/h or 120 km/h (the maximum moving speed of a terminal described in IEEE 802.16e standard), then the benefits resulting from applying the proposed method are slightly lower, however still significant. The best results have been achieved for the CDFQ method and Vehicular A model of channel, $\boldsymbol{v}$=60 km/h, which matches the speed of users travelling in vehicles in typical traffic [9][10].

6. Conclusion

The paper discusses selected test results of data scheduling methods and subcarrier allocation used in networks operating according to WiMAX Mobile standard. The simulations have been conducted for the following methods: WRR, PF and CDFQ. The tests allow us to formulate the conclusion that using parameters describing current radio conditions and operating conditions in CDFQ method results in greater efficiency of scarce physical resources in the access network.

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