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MAC Scheduling for Fixed Broadband Wireless Access Systems

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Abstract. *Fixed broadband wireless access systems will play an important role in the liberalised telecommunications market since their main advantage is fast set-up with low cost. The basic characteristic of such system is the sharing of the access medium (radio medium) among the users. We have to distinguish between the uplink and downlink direction of the communication. The downlink flows are simply multiplexed by the access point and there is no contention. The uplink direction is more challenging since the medium access control protocol is needed to minimise the contention probability. The medium access control protocol also has to include the uplink scheduling in order to accommodate the demand assignment multiple access and dynamic resources allocation. With the introduction of the IP QoS models such as IntServ, layer two (especially MAC protocol) has to be able to guarantee the parameters such as minimum bit rate. Within our studies we developed the OPNET simulation model for wireless IP simulation (integrated with OPNET IP, TCP and traffic source models). The results presented show the performance of the FTP upload with different reserved uplink minimum bit rates.*

Keywords: broadband wireless communications, medium access control protocol, uplink scheduling, IP over wireless

1 Introduction

The access to the public and private broadband networks is becoming increasingly important. Among various systems the Fixed Broadband Wireless Access (FBWA) systems are going to be the most flexible access systems. Their main advantages are, among others, fast deployment, dynamic sharing of radio resources and low cost.

The broadband wireless access systems typically use licensed microwave or millimetre wave frequencies to connect the network nodes to fixed user sites through a rooftop antenna. There are many kinds of broadband wireless access possibilities:

- **Point-to-point:** is intended for a single user connection, normally with a dedicated high bandwidth.
- **Point-to-multi-point:** a single base station serves a number of terminals in a certain area (cell). The users can share the bandwidth by bandwidth-on-demand capability.
- **Satellite-based platforms:** they can provide very broad earth coverage, typically partitioned into numerous cells, thus enabling frequency reuse and more efficient utilisation of allocated bandwidth. Still, because it is shared over a large area, the available bandwidth is not likely to provide the broadband wireless access to a large number of users. Thus, satellite-based platforms are of great importance mainly for rural and remote areas, and will most likely be restricted to lower transmission speeds.
- **Stratospheric platforms:** while sharing many characteristics with satellite-based platforms, these systems are expected to provide broadband access to metropolitan areas. Their main advantages are smaller coverage area, fast deployment, simple cell planning, little ground-based infrastructure, suitability for the provision of broadcast and multicast services, low propagation delay, small size of antenna, broadband capability, etc. In addition, the position of stratospheric

platforms can be moved in compliance with communication demand providing access network flexibility and re-configurability. At the moment, however, they lack more mature technology.

Most notable advantages of wireless access over its wired counterpart are fast deployment, which supports easier entry into new markets, and the fact that the major part of costs is due to electronics and not labour. But there are also disadvantages such as the need to establish the line-of-sight, service availability is subject to weather effects, aesthetics of consumer antenna and community base stations, and lack of standards.

Currently, the products exist for the Multipoint Multichannel Distribution System (MMDS) and Local Multipoint Distribution System (LMDS). However, there are also emerging standards such as IEEE's Broadband Wireless Access (BWA), ETSI's HIgh PErformance Radio ACCESS (HIPERACCESS) and HIgh PErfomance Radio MAN (HIPERMAN).

In this paper some issues concerning broadband wireless access systems are presented. At first FBWA scenario and Medium Access Control (MAC) protocols are introduced. Then an uplink scheduling with two proposed algorithms is described. The last part deals with the wireless IP access simulation model, which has been developed with the Optimized Network Performance (OPNET™) Modeler simulation tool [1].

2 Fixed Broadband Wireless Access

FBWA system consists of the access point, usually called Base Station (BS), and Subscriber Stations (SSs) as shown in Figure 1. In this scenario SS can either be an individual end user terminal or a group terminal with several end user terminals connected to it. All data traffic goes through the BS, and because of that BS can control the allocation of bandwidth on the radio channel. The FBWA systems are Bandwidth on Demand (BoD) systems, which means that SSs have to request the bandwidth, which is then scheduled and allocated according to the agreed traffic and QoS parameters by the BS.

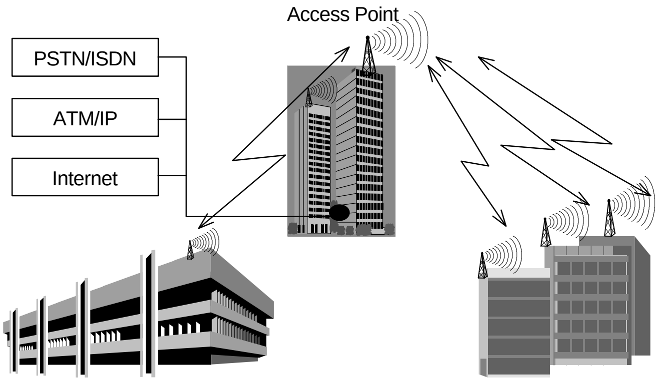

Figure 1: Fixed BWA scenario

The market addressed by the FBWA systems is similar to wire or fiber- based broadband access technologies. The most similar system is digital cable TV hybrid fiber/coax (HFC) technology since the capacity is shared between the users. The usual bit rates of the carriers are between 25 and 155 Mbps. The following applications can be supported by FBWA system: digital audio/video multicast/broadcast, digital telephony, IP protocol based applications, bridging of LAN islands, ATM protocol based applications, point-to-point connections, etc.

3 Protocol Stack

Modern access systems support different higher layer protocols. The protocol stack for BWA systems follows a convergence sub-layers strategy. This means that different upper layer protocols are placed in parallel, e.g. IP is not transmitted over ATM, as shown in Figure 2. MAC protocol offers the services to different convergence sub-layers. For every upper layer technology different convergence sub-layer is needed. The main tasks of the convergence sub-layers are:

- Mapping of the upper layer's address into MAC addresses,

- Translation of the upper layer's CoS/QoS into MAC CoS/QoS,
- Conversion of higher layer packets with a variable or fixed size into MAC layer packet size.

<table>
<tr><td>IP</td><td>Ethernet</td><td>ATM</td><td>Video</td></tr>
<tr><td>IP Convergence</td><td>Ethernet Convergence</td><td>ATM Convergence</td><td>MPEG Convergence</td></tr>
<tr><td colspan="4">Medium Access Control Layer</td></tr>
<tr><td colspan="4">Physical Layer</td></tr>
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Figure 2: Protocol stack for BWA system

The central purpose of the MAC protocol is sharing of radio channel resources. The MAC protocol defines how and when an access point or subscriber unit may initiate the transmission on the channel. The MAC protocol includes the interface's procedures to provide guaranteed services to upper layers. Especially the uplink direction is very complex since the MAC protocol has to resolve the contention and bandwidth allocation efficiently. An optional part of the MAC layer is also error control, which usually includes Forward Error Correction (FEC) or a variant of the Automatic Repeat Request (ARQ) protocol, which ensures a reliable transmission over radio interface.

4 MAC Protocols

Wireless medium is a shared medium, which demands the Medium Access Control (MAC) protocol to co-ordinate the transmission of multiple traffic flows over it. From the architecture point of view the MAC protocols can be *distributed* or *centralised*. However, for the FBWA scenario the centralised approach is preferred since the access point, which is always connected to the access backbone network, co-ordinates the uplink and downlink transmission.

The basic distinction between different MAC protocols is the duplexing of the uplink and downlink channels. There are three approaches to implement it:

- *Time Division Duplex (TDD)*: the downlink and uplink channels use the same carrier frequency. The MAC frame is divided into portions. The border between the uplink and downlink portion can be adaptive, what makes it very suitable for asymmetric connections.
- *Frequency Division Duplex (FDD)*: in the downlink and uplink different carrier frequencies are used. The terminals simultaneously transmit and receive the signals.
- *Half-duplex Frequency Division Duplex (H-FDD)*: Different carrier frequencies are for the downlink and uplink transmission, but the terminals do not transmit and receive simultaneously. This poses a challenging problem to the uplink and downlink resource management.

The type of the physical channel has a significant influence on the radio access protocol and scheduling algorithms. There are three types of physical channels for downlink transmission [2]:

- *Continuous transmission channel*: the traffic flow is transmitted in the downlink as it is received by the access point from the access network. The access point does not broadcast any information about the location of the data within the downlink flow. Therefore, the terminals have to decode the whole flow and pick up the packets addressed to them.
- *Time Division Multiplexing (TDM) stream channel*: With the continuous transmission channel the problem arises when the modulation type is changed within one MAC frame since the change of the modulation type has to be announced at the beginning of MAC frame. The packets intended for various terminals have to be re-ordered according to the modulation type used by a particular terminal.
- *TDMA burst channel*: This mode allows the standby mode when the data is not addressed to the particular terminal. The frame structure is announced at the beginning of the MAC frame.

In the uplink direction only one type of physical channel is possible, because of the multiple access:

- *TDMA burst channel*: For the efficient utilisation of the uplink resources it is advantageous that a terminal transmits all data within one MAC frame in a burst. The first advantage is a reduction of required guard times. In this case the guard time is only needed at the beginning of the burst. The second advantage is a reduced signalling due to the uplink reservations since the pointers can be used to mark the beginning of the burst.

For the MAC protocol the following sharing methods are available:

- *Dedicated assignment*: The resources are allocated from the connection set-up to the connection release.
- *Random access*: The terminals contend for the resources randomly upon the transmission request.
- *Demand-based assignment*: The resources are assigned according to the requests for resources, which are sent by the terminals. The requests can be transmitted over dedicated (out-of-band) channels, random channels, or piggybacking (in-band) channels. The access point can use the polling technique giving the opportunity to the terminals to send the requests for resources without contention.
- *Free assignment*: MAC scheduler can use some heuristic method to allocate the resources, which remain available after all resource requests have been served.

Figure 3 shows an example of the FDD based MAC protocol. The downlink and uplink MAC frame length is of constant length. The downlink structure begins with the broadcast phase where the information about uplink and downlink structure is announced. The structure of downlink and uplink phase can be changed from frame to frame because of the statistical multiplexing and bandwidth on demand. The random access area in the uplink is primarily used for the initial access but also for the signalling when the terminal has no resources allocated within the uplink phase. Within the uplink phase the data MAC packets and MAC mini slots, which are used for the signalling and resource requests (out-band signalling), are transmitted. For the TDMA transmission mode it makes sense to group all mini-slot and data packets in order to mitigate the guard time before transmission. However, this kind of transmission has a great influence on the QoS parameters such as delay variation, especially for real time applications.

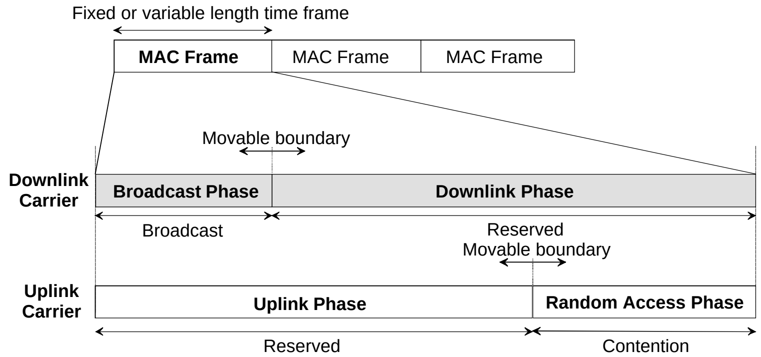

Figure 3: FDD based MAC protocol

The wireless medium resources have to be scheduled according to the traffic and QoS parameters, in order to support statistical multiplexing. The scheduling can be divided into downlink and uplink scheduling. In the downlink the flows are simply multiplexed and therefore the standard scheduling algorithms can be used, such as Weighted Round Robin (WRR), Weighted Fair Queuing (WFQ), Virtual Time (VT), Deficit Round Robin (DRR), etc [3].

5 Uplink Scheduling

The uplink scheduling algorithm is responsible for the efficient and fair allocation of the resources (time slots) in the uplink direction. Unfortunately, the uplink scheduler, which is situated in the access point, has no data about the arrival times of the packets or cells, which are buffered in the user terminals waiting for the uplink transmission.

In the recent years several uplink scheduling algorithms have been proposed [4], [5], [6]. However, the proposed algorithms often presume that packet arrival times are available to the uplink scheduler. Therefore they cannot be practically implemented. Since our aim was to integrate the scheduling algorithms with the realistic MAC protocol, we adapted the scheduling techniques, which do not need the packet arrival times.

In this paper we propose two uplink scheduling algorithms, which are able to guarantee the minimum bit rate of the particular traffic flow and can be very easily implemented. The same algorithms in a combination with a token bucket process can also guarantee the requested mean bit rate.

It is very important to point out that the scheduling algorithms can guarantee QoS (e.g. minimum bit rate) only if the number of flows is limited via connection admission control. The sum of the minimum bit rates of all connected flows must be lower than the capacity allocated to the applications within the same QoS level.

Regarding the required QoS level we need to distinguish two kinds of applications, real-time applications and non-real-time applications, respectively. For the first one it is very difficult to guarantee the jitter of packet delay. One of the solutions to remove the jitter is the use of traffic shaping for each non-aggregated traffic flow. The non-real time applications, on the other hand, require the reliability of the transmission. In this case the aggregated traffic flows can use one ARQ connection over the radio interface.

5.1 IP Quality of Service Mapping to Layer 2 Quality of Service

There are two QoS/CoS models defined for IP technology. The first one is IntServ model, which provides three types of services: best effort, controlled load and guaranteed quality of service. For the last two types of services the resources can be reserved per-flow. For both, controlled load and guaranteed quality of service, classes the traffic specification (estimated) is needed for the resources reservation along the IntServ connection.

The second IP QoS/CoS is the DiffServ model, which provides only coarse QoS guarantees. The combination of the Service Level Agreement (SLA), tariff model and DiffServ model can provide a flexible BoD system with efficient radio resources management.

Basically, the IntServ QoS/CoS model is more appropriate for the mapping on MAC layer QoS/CoS parameters since the mean bit rate is set to exact value. That’s not the case for DiffServ model, where first the priorities have to be mapped to appropriate bit rates.

5.2 Uplink Scheduling per Flow or per Subscriber Station?

In FBWA system there are two important issues indicating the importance of the uplink scheduling location. Firstly, the use of group terminals (more that one user terminal is connected to it), which will be predominantly installed for the business user and local communities. And secondly, the multimedia applications usually involve more than one traffic flow with different traffic and QoS parameters.

The majority of the scheduling functions must be located in the access point, since the FBWA system has a centrally based architecture. The access point scheduler is able to schedule the user traffic per each flow or per SS. However, in the second case the SS has to schedule the traffic of the user terminals connected to it. SS must also inform or renegotiate the parameters of the MAC connection between the SS and the access point with the access point. SS can use the well-known scheduling algorithms used in Asynchronous Transfer Mode (ATM) switches or Internet Protocol (IP) routers.

In the following we propose two scheduling algorithms that can be used with per flow or per SS scheduling strategies. They both guarantee a minimum bit rate and are independent of the signalling.

5.3 Virtual Weighted Round Robin

The Virtual Weighted Round Robin (VWRR) uplink scheduling algorithm can be implemented in a similar way as the WRR algorithm [3]. Figure 4 shows the graphical representation of the VWRR. In each scheduling cycle (the beginning of the downlink MAC frame) the scheduler visits the `Slots_Requested_Counter` of the particular connection (or terminal) in a round robin manner.

In the case that both, the `Slots_Requested_Counter` and `Weight_Counter`, are greater than zero, the time slot is allocated and both counters are subtracted by one. The process ends when all available time slots are allocated or all resource requests are served. The pointer `last_RR` is very important since it points to the flow which was last served. For the proper functioning of this algorithm one parameter is still needed which represents the sum of connection's weights. This parameter is implemented in the form of a counter, which is also subtracted by one in each cycle and is called VWRR frame length. The other two counters are not subtracted if one of the following counters is zero: `Slots_Requested_Counter` or `Weight_Counter`. When the VWRR becomes zero, all counters are reinitialised.

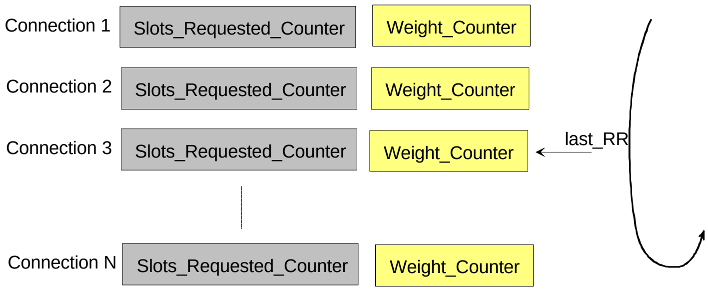

Figure 4: Virtual WRR scheduling representation

5.4 Virtual Virtual Time

The Virtual Virtual Time (VVT) uplink scheduling has been adopted from the Virtual Time (VT) scheduling. The word virtual is added since the virtual times for the arrived packets are not determined at the packet arrival into the buffer of the user terminal, but according to the resource requests by the scheduler in the access point. Basically the virtual time is calculated for each resource request according to the uplink minimum bit rate as shows the following equation:

$$VT_i^k = VT_i^{k-1} + \frac{L_i^k}{r_i} \qquad (1)$$

Equation (1) represents the virtual time of the *k*-th packet of the *i*-th flow with the bit rate r_i. *L* stands for the packet length. Each virtual time is put into the sorted list of the virtual times with the corresponding flow identifier. Unfortunately, the size of the sorted list is not of the constant length. To overcome this problem, the VVT algorithm first searches for the slowest flow and puts its first virtual time into the sorted list as shown in Figure 5. Then the VVT algorithm determines the virtual times for all other flows, which are lower than the first virtual time of the slowest flow. This procedure is repeated until all available uplink resources are allocated or all resource requests are served. At the end, the virtual time inputs for each flow are counted within the first *N* elements (number of MAC data packets, which can be allocated). This information is then broadcast to all SSs.

At least two problems can occur with the VVT scheduling. The first problem is the accumulation. It occurs when a particular flow does not have any packets to send for some time. In that case the last virtual time is much lower than the actual time. Since we do not allow accumulation for the minimum bit rate guarantee, the equation (1) for the virtual time, which is used by the scheduler at each Scheduling Time (*ST*), is upgraded as shown in equation (2):

$$VT_i^k\,(\text{first of the scheduling cycle}) = \max(VT_i^{k-1}, ST - \frac{L_i^k}{r_i}) + \frac{L_i^k}{r_i} \qquad (2)$$

It can be obtained that the last virtual time gets the value of the actual time of the packet arrival time (in our case, because of the uplink scheduling, the real time of the beginning of the scheduling).

The second problem is the starving of a particular flow when at the particular moment a given flow has much greater virtual time than other flows. In such a case the solution is to set the virtual time of the first resource request according to equation (3):

$$if \;\; VT_i^{k-1} > ST + \frac{L_i^k}{r_i} \quad then \quad VT_i^k (\text{first of the scheduling cycle}) = ST + \frac{L_i^k}{r_i} \qquad (3)$$

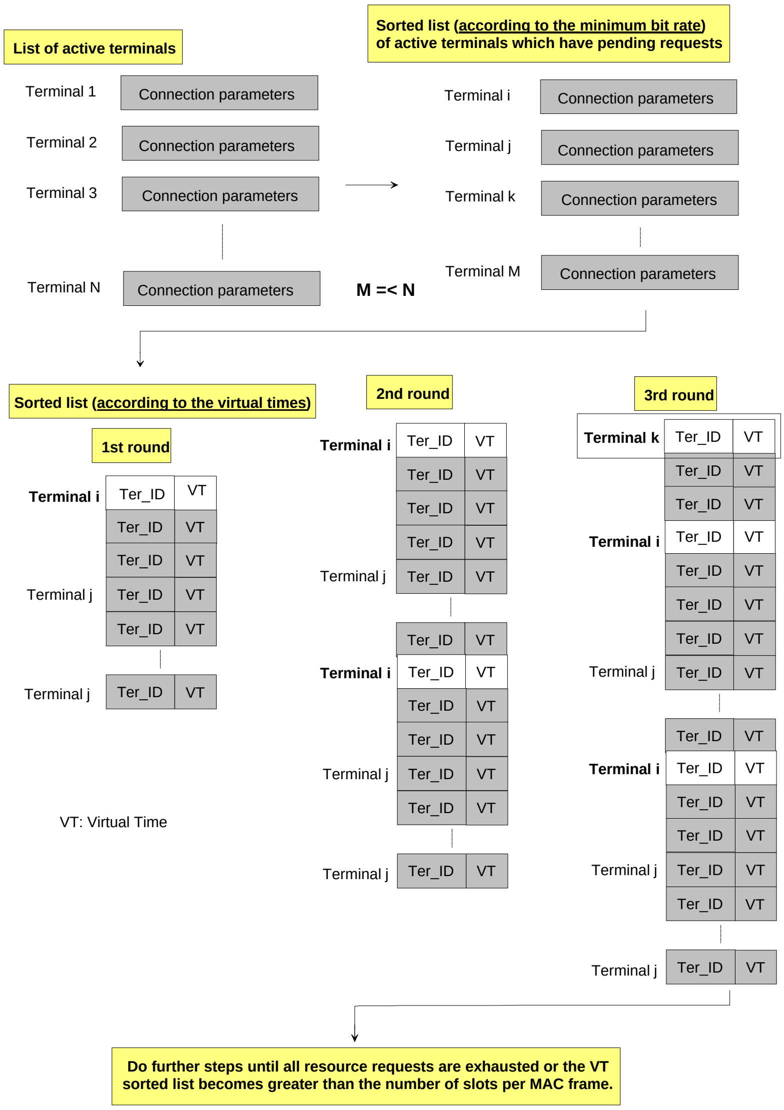

Figure 5: Virtual virtual time scheduling representation

6 Simulation Model for the IP based FBWA System

For the simulation of the proposed scheduling algorithms the Wireless IP (WIP) model has been developed with the OPNET^{TM} Modeler tool, which is a primary product of the OPNET Technologies, Inc. It can be described as a discrete event based modeling and simulation tool. The key features of OPNET Modeler are the following:

– It is object oriented, where each object has a defined set of configurable attributes.
– It employs a hierarchical approach to modelling, having three separate levels (network level, node level and process level) to describe any communication network.
– Detailed library models provide support for existing protocols such as ATM, IPv4, TCP, HTTP, etc. and allow researchers and developers to either modify the existing models or develop new models.
– A simulation code can be debugged on different levels such as protocol or algorithm level.

The simulation model is organised in a hierarchical manner consisting of three structural levels:

- *Network model level*: Figure 4 shows the WIP simulation model with four wireless IP terminals, access point, IP network and servers. The profile and application modules are used for the definition of the user applications simulated in the WIP terminals.

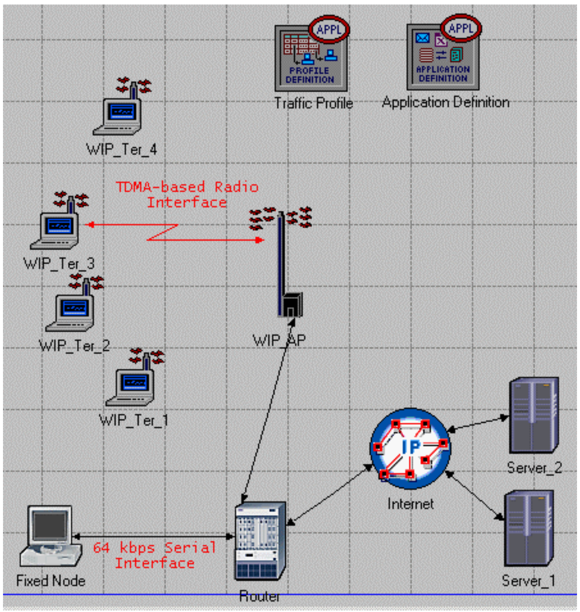

Figure 6: WIP OPNET simulation scenario

- *Node model level*: The node level represents the whole protocol stack of the network elements as shown for the WIP user terminal in Figure 5. For the WIP simulation the MAC protocol has been developed and is integrated with OPNET Address Resolution Protocol (ARP) level, which is located below the IP layer.

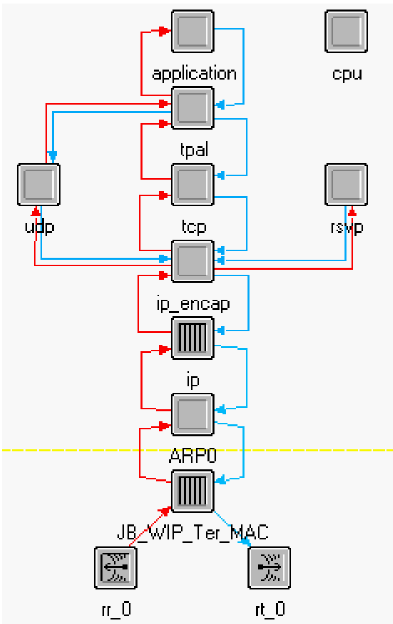

Figure 7: WIP terminal node model level

- *Process model level*: The MAC process consist of the parent MAC process shown in Figure 6 and child process which is responsible for the MAC connection set-up. The task of the MAC process is the co-ordination of the medium access and segmentation (re-segmentation) of IP packets into MAC packets of constant length. Since the IP technology is connection-less the parameters for the MAC connection are defined independently. For the MAC connection set-up the principle with the holding time is used as for the IP over ATM [7].

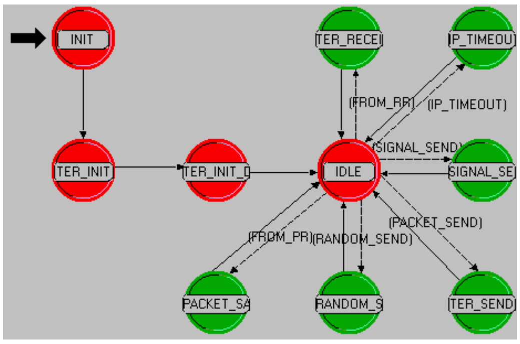

Figure 8: WIP terminal MAC process model

The simulated MAC protocol of the WIP simulator is based on: (i) FDD with periodic broadcast phase in the downlink, (ii) continuous transmission mode in the downlink phase, and (iii) TDMA mode in the uplink phase and contention phase. The uplink TDMA mode uses bursts, which are composed of the guard time (switching between different users), mini-slot (used for the resource requests) and data slots. The number of the data slots in a particular burst varies from frame to frame as it is determined by the uplink scheduler. In this way, the MAC protocol is the demand assignment based multiple access.

7 Simulation Results

The presented simulator allows the simulation of any TCP/UDP/IP based client-server application. The results in Figure 9 show the response times of the FTP upload application for the terminals with different minimum bit rates. The following parameters have been applied:

- MAC parameters:
  - Uplink bit rate: 2 Mbps,
  - Downlink bit rate: 64 Mbps,
  - MAC frame length: 24 ms,
- FTP file size: 1 Mbyte.

The terminal one has a minimum bit rate of 1 Mbps, terminal two 0.5 Mbps, terminal three 0.3 Mbps, and terminal four 0.2 Mbps. All terminals start their FTP session with minor difference in the start time. For both, the VWRR and VVT the results are practically identical. The difference between the implemented scheduling techniques is the implementation and the complexity of the processing at each scheduling cycle.

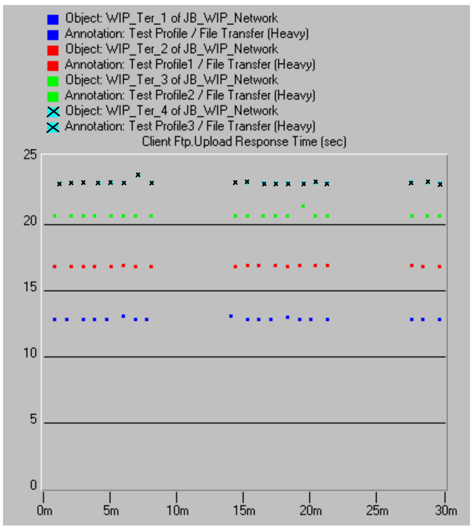

Figure 9: FTP upload response time for terminals with different minimum bit rates (VWRR or VVT uplink scheduling) (x-axis represents the simulation time in minutes, and y-axis represents the response time in seconds)

8 Conclusions

The uplink scheduling is a challenging issue for the FBWA systems, especially when the differentiation between the applications and user in terms of traffic and QoS parameters is needed. In the paper two scheduling algorithms, which can guarantee minimum bit rate, have been proposed. They have been implemented and tested with the OPNET^{TM} simulation tool. In a combination with the separate token bucket process for each terminal (connection) the proposed algorithms can also guarantee the mean bit rate. However, the minimum and mean bit rate scheduling have to be performed separately.

Further research is required for the development of the efficient signalling of the traffic and QoS parameters required over the radio interface. The dimensioning is also an important issue because the QoS can not be supported without efficient connection admission control.

References

[1] Http://www.opnet.com

[2] J. Foerster, Recommended Changes to the Draft 802.16.1 Physical Layer Document, June 2000. `http://www.ieee802.org/16.`

[3] H. Zhang, Service Disciplines for Guaranteed Performance Service in Packet-Switching Networks. *Proceedings of the IEEE*, Vol. 83, pp. 1374-1396, October 1995.

[4] T. S. Eugene Ng, I. Stoica, and H. Zhang, Packet Fair Queuing Algorithms for Wireless Network with Location-Dependent Errors, In *Proc. INFOCOM98*, pp. 1103-1111, March 1998.

[5] S. Lu, and V. Bharghavan, Fair Scheduling in Wireless Packet Networks, *IEEE/ACM Trans. Networking*, Vol. 7, no. 4, pp. 473-489, 1999.

[6] Y. Cao, and V. O. K. Li, Scheduling Algorithms in Broad-Band Wireless Networks, *Proceedings of the IEEE*, Vol. 89, pp 76-86, January 2001.

[7] RFC 1755, ATM Signaling Support for IP over ATM, February 1995. `http://www.ietf.org.`