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Handover Simulation in a Mobile WiMAX Network

Octavian Fratu[1], Roxana Cîrstea[1], Simona Halunga[1],

Abstract – The paper is presenting a simulation procedure of the handover into Mobile WiMAX networks and its hybrid extension based on WiFi technology. The transmitted data jitter and the end-to-end delay are analyzed.
Keywords: handover, WiMAX, QualNet

I. INTRODUCTION

The technology commonly named as WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunication technology with the goal of delivering ”last mile” fixed, nomadic, portable and mobile wireless connections on a metropolitan scale.
WiMAX is based on wireless metropolitan area networking (WMAN) standards developed by the IEEE 802.16 group and adopted by both IEEE and the ETSI HIPERMAN group. The IEEE 802.16 group was formed in 1998 to develop an air-interface standard for wireless broadband. The group’s initial focus was the development of a LOS-based point-to-multipoint wireless broadband system for operation in the 10GHz–66GHz wave band.
The IEEE 802.16 group produced the 802.16a, an amendment to the standard, to include NLOS applications in the 2GHz–11GHz band, using an orthogonal frequency division multiplexing (OFDM. Additions to the MAC layer, such as support for orthogonal frequency division multiple access (OFDMA), were also included. In December 2005, the IEEE group completed and approved IFEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support. The IEEE 802.16e-2005 forms the basis for the WiMAX solution for nomadic and mobile applications and is often referred to as mobile WiMAX.
One of the largest applications of WiMAX is broadband access for residential, small office/home office, and small to medium enterprises. Broadband services provided using fixed WiMAX include high-speed Internet access, telephony services using voice over IP, or other Internet-based applications. Fixed wireless offers several advantages over traditional wired solutions. These advantages include lower deployment costs; faster and easier deployment and revenue realization, ability to build out the network as needed; lower operational costs for network maintenance, management, and operation.
Another major opportunity for fixed WiMAX in developed markets is as a solution for competitive T1/E1, fractional T1/E1, or higher-speed services. It is known that only a small fraction of commercial buildings worldwide have access to fiber so there is a clear need for alternative high-bandwidth solutions for enterprise customers.
An interesting opportunity for WiMAX is the potential to serve as the backhaul connection to the Wi-Fi hotspots. In developed markets, a growing number of Wi-Fi hotspots are being deployed in public areas such as hotels, airports, and coffee shops. The Wi-Fi hotspot deployments are expected to continue to grow in the coming years. Most Wi-Fi hotspot operators currently use wired broadband connections to connect the hotspots back to a network point of presence. WiMAX could serve as a faster and cheaper alternative to wired backhaul for these hotspots.
Although initial WiMAX deployments are likely to be for fixed applications, the full potential of WiMAX will be realized only when used for nomadic and mobile broadband applications. Because end users get a custom access to high-speed broadband at home and work, they will demand similar services in a nomadic or mobile context, and many service providers could use WiMAX to meet this demand.
The WiMAX Forum has defined a reference network architecture that is based on an all-IP platform. All end-to-end services are delivered over an IP architecture relying on IP-based protocols for end-to-end transport, QoS, session management, security, and mobility. Reliance on IP allows WiMAX to facilitate easy convergence with other networks, and exploit the rich number of IP-based applications.

II. SCENARIO-BASED INVESTIGATION

In order to reveal the procedure of handover in WiMAX networks and its limits and performances, a dedicated scenario was developed. On the other hand, if the scenario is general enough, it is representative and could be considered as a suitable method to investigate the network and the system capabilities

[1] Facultatea de Electronică, Telecomunicaţii şi Tehnologia Informaţiei, Universitatea POLITEHNICA din Bucureşti, Catedra de Telecomunicaţii, Splaiul Independenţei nr. 313, e-mail: {ofratu,rcirstea,shalunga}@elcom.pub.ro

and performances. For a general approach, it will be necessary an intensive study considering different parameters and environmental conditions for the defined scenario.

The proposed scenario is implemented in QualNet, a software tool supporting scalable simulations of numerous types of wireless protocols. QualNet uses a layered structure, much like the Open Systems Interconnection (OSI) seven layer network stack. QualNet Developer provides an environment for designing network protocols, creating and visualizing network scenarios under specified conditions.

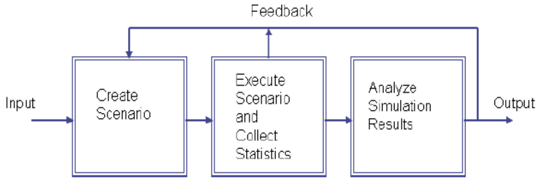

Fig. 1 Simulation steps

In general, a simulation study includes three phases. The first phase is to create and prepare the simulation scenario based on the system description and metrics of interest. The second phase is to execute the created scenario and collect simulation results. The last phase is to analyze the simulation results. Typically, users may need to adjust the scenarios based on the observations from the second and third phases (fig. 1).

Creating a scenario can be divided into several steps focusing on different aspects. First of all, the general properties applicable to the whole scenario must be configured. Then, the network topology must be specified by creating subnets, placing nodes, and defining node mobility. The third step is to configure the protocol stack for individual nodes or groups of nodes and then to set parameters for collecting simulation results and controlling runtime performance (fig. 2).

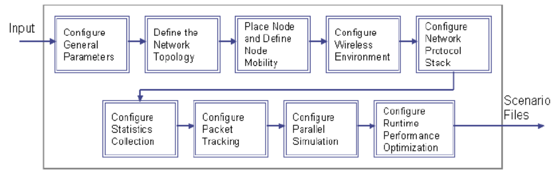

Fig. 2 Steps in creating a scenario

III. NETWORK TOPOLOGY AND PARAMETERS

The network topology used for the simulation consists of (fig. 3):

- four BSs that cover different and non-overlapping areas (BS1, BS2, BS3, BS4)
- a switching centre that connects to every one of the four base stations using a wired connection (Switching Centre)
- Mobile user - a mobile node that moves on a preset way basis (the MS follows the waypoints on the map by taking into account their placement order)
- a fixed node towards the MS is moving (Home)

The simulation uses the physical layer and MAC layer defined in QualNet for the IEEE 802.16 standard. For every node used in the scenario, there will be specified the parameters used in this simulation.

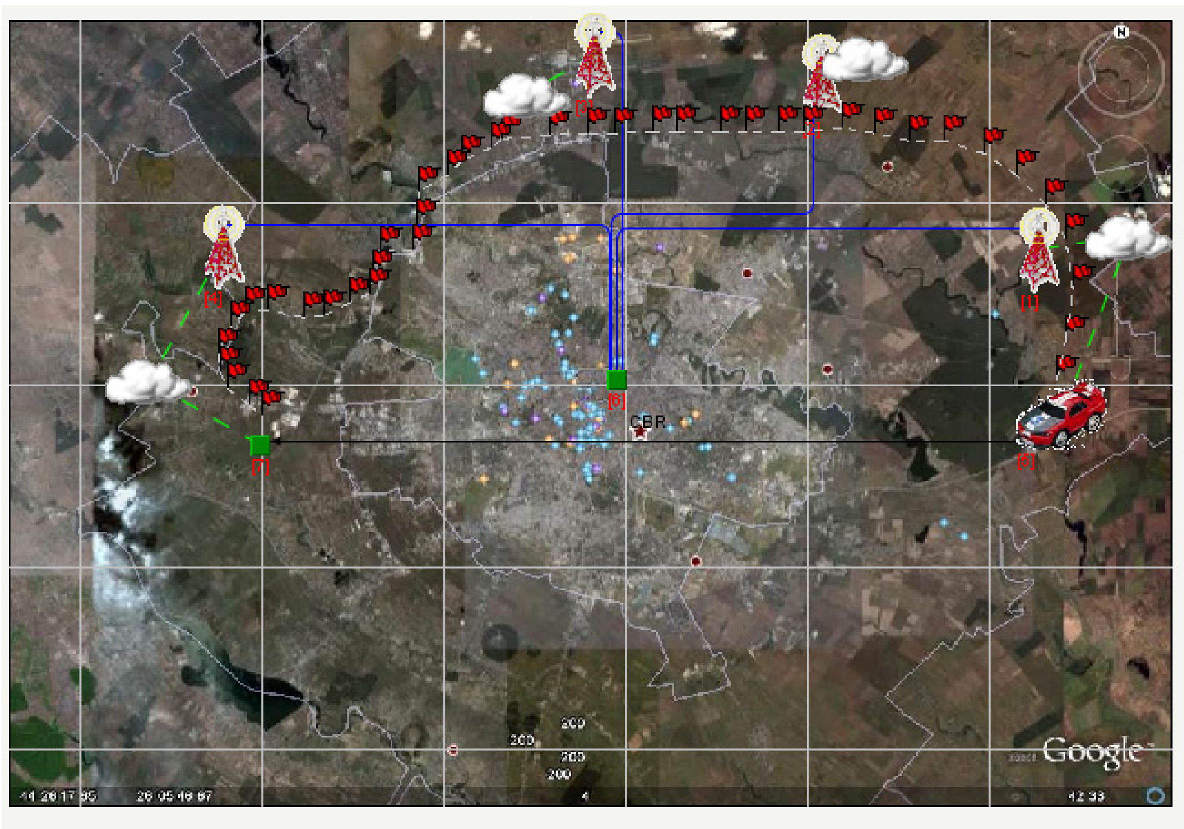

Fig. 3 Node placement in QualNet

For a base station the physical layer parameters are: radio type – 802.16 Radio, transmission power-20dBm, packet reception model – PHY802.16 and the antenna model – omnidirectional, 12dB gain, 10m height, antenna efficiency 0.8, antenna mismatch loss 0.3dB, antenna connection loss 0.2dB. The figure 4 concentrates the MAC layer protocol parameters used when configuring a BS.

Properties of Statio [Properties of Station Type *]

Station Type *	Base Station
• MAC Frame Duration	20MS
• TDD Downlink Duration	10MS
• DCD Broadcast Interval	(r/w) MAC-802.16-BS-FRAME-DURATION
• UCD Broadcast Interval	5S
• Ranging Minimal Backoff Value	3
• Ranging Maximal Backoff Value	15
• Bandwidth Request Minimal Backoff Value	3
• Bandwidth Request Maximal Backoff Value	15
• Service Flow Timeout Interval	15S
• Transmit/receive Transition Gap(TTG) *	75US
• Receive/transmit Transition Gap(RTG) *	75US
• SS Transition Gap(SSTG) *	75US
• Maximum Allowed Uplink Load Level	0.7
• Maximum Allowed Downlink Load Level	0.7
• Packing Enabled *	Yes
• Admission Control Scheme	NONE
• Ranging Type	NORMAL
• Contention Based Bandwidth Request Type	NORMAL

Fig. 4 MAC layer parameters for a BS

In order for the BS to be aware of the MS's movement it should support a mobility mode. To experience a handover procedure, a base station needs to know the neighbouring BS list. This neighbour list is configurable in QualNet for every BS. In addition to this, three other parameters are specified: neighbour BS scanning RSS trigger (-76dBm), handover RSS trigger (-78dBm) and handover RSS margin (1dBm).
For the mobile node the layer 1 parameters and some of the layer 2 parameters are similar with the ones configured for a BS. The difference is that the mobile node is configured as a subscriber station and this can be seen in the next figure. The MS supports a mobility mode (802.16e) and its movement is controlled by placing waypoints on the map. During its movement, the MS follows the waypoints in the same order they were placed on the map. The MS has a constant speed between two waypoints and a straight movement toward the next waypoint.

Station Type *	Subscriber Station
• Wait DCD Timeout Interval	25S
• Wait UCD Timeout Interval	25S
• Service Flow Timeout Interv	15S
• Packing Enabled *	Yes
• Ranging Type	NORMAL
• Contention Based Bandwidtl	NORMAL

Fig. 5 MAC layer parameters defined for a subscriber station

For every BS, there is a subnet defined. In total, there are four subnets: 192.0.0.0, 192.0.1.0, 192.0.2.0, 192.0.3.0. Other important parameters are: channel bandwidth 20MHz, FFT size 2048, cyclic prefix factor 8.

- Other important parameters defined for this simulation in connection with the wireless subnet are: channel frequency 2.5GHz,
- propagation limit -111dBm,
- Two ray pathloss model.

Signals having a power level bellow the propagation limit (without receiver antenna gain) are not delivered.
To be able to observe and analyze the WiMax network, a CBR traffic flow was generated. The traffic source node is the mobile node and the destination of this traffic is the fixed node. WiMAX compliant systems can support Constant Bit Rate (CBR) by configuring dedicated frequency-time channel grants to specific traffic flows. The dedicated resources correspond to a constant throughput rate. CBR service flows are suitable for applications with strict latency and throughput constraints. These applications generate a steady stream of fixed size packets such as VoIP.
For the downlink, the BS directly controls the scheduling of traffic and allocation of the frequency-time channel resources. Dedicating a portion of the channel bandwidth for CBR flows is therefore a matter of keeping track of the allocated resources. For the uplink, the Unsolicited Grant Service (UGS) scheduling method is used. The BS dedicates a portion of the uplink channel bandwidth to a MS corresponding to one or more service flows for the duration of the flow. The BS communicates this assignment to the MS in the uplink channel usage maps that are periodically broadcast out to all stations. The key CBR QoS parameter is the fixed Maximum Sustained Traffic Rate, which is the committed information rate for the flow. The maximum rate is unconditionally dedicated to the flow and therefore can be directly subtracted from the available user channel size to determine the remaining capacity. The only overhead associated with CBR flows is the UGS grant overhead, which increases the size of the uplink channel usage map.
Although the bandwidth is dedicated for a CBR service flow, the BS can temporarily "borrow" the dedicated bandwidth on the downlink frame if there is no CBR traffic to send. The scheduler must however issue uplink grants according to the CBR service flow configuration whether or not the subscriber station has any traffic to send.
Figure 6 contains the CBR parameters I have set for this simulation. This means that the source node 5 is sending 512-byte packets to destination node 7 every 0.01s, during a 90 s (96(CBR traffic flow end time)-6(CBR traffic flow start time)). To summarize, this means:

- (90/0.01)*512= 4608000= 4.608*10^6 bytes sent;
- (4.608*8*10^6)/90=0.4096*10^6 bits/s theoretical throughput

IV. SIMULATION SCENARIO AND RESULTS

The scenario was developed for two purposes. The first was to facilitate measurements of WiMAX processes like handover. The second purpose was to evaluate QualNet as a possible environment for future development and testing of WiMAX networks.

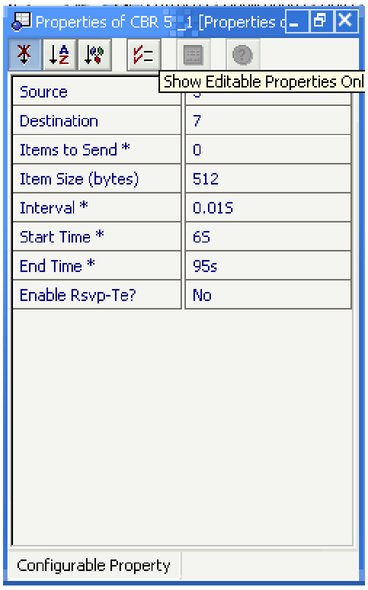

Fig. 6 CBR parameters

The developed scenario consists of a mobile node performing network entry and then moving toward a fixed node. During its movement, the mobile node passes through different base stations coverage areas. There are four BSs placed in such a way that the MS can perform only three handovers until it gets to the destination and without performing another network entry. During this phase the MS performs ranging and negotiates capabilities with a BS. The end result is a setup of management and transport connections between the BS and MS.

A. *The handover procedure*

Because of the MS's movement, the signal level drops bellow the preset threshold and the handover procedure is imminent. The handover requires communication with both BSs and a frequency change for the MS. Before and after the handover is completed the data traffic shall continue uninterrupted, with the flow of data now moved from one BS to another after a completed handover. This type of handover is basically performed by releasing the associated BS and then performing network entry at another BS.

In order for the handover to become possible, communication between the nodes of the network must exist. To demonstrate that the base stations included in this scenario exchange messages between them it is useful to take a look at the figure 7. It can be seen that every one of the four BSs exchange hello messages with the other three of them and the messages arrive at the destination.

A mobile node listens to L2 (link-layer) messages and a BS periodically broadcasts a Neighbour Advertisement Messages (MOB-NBR-ADV) for network identification and to define the characteristics of the neighbour BS. . The purpose of this message is to inform all listening stations of the characteristics of any neighbouring base stations, which they may or may not wish to move to. The frequency of the BS, its BS identifier, the types of services it supports and its available radio resources (available channels etc.) are just a few parameter examples included in the MOB-NBR-ADV message. This message is transmitted on the broadcast connection. An important parameter of this message is the frequency with which it is sent. The IEEE 802.16e standard specifies a maximum of 1s. This is intuitive because if we have a mobile station moving at large speed, it may be moving through the range of coverage of each BS quicker than it receives the MOB-NBR-ADV message. In this case, the MS would be unable to perform handover. This parameter is limited by the MS moving speed through the network.

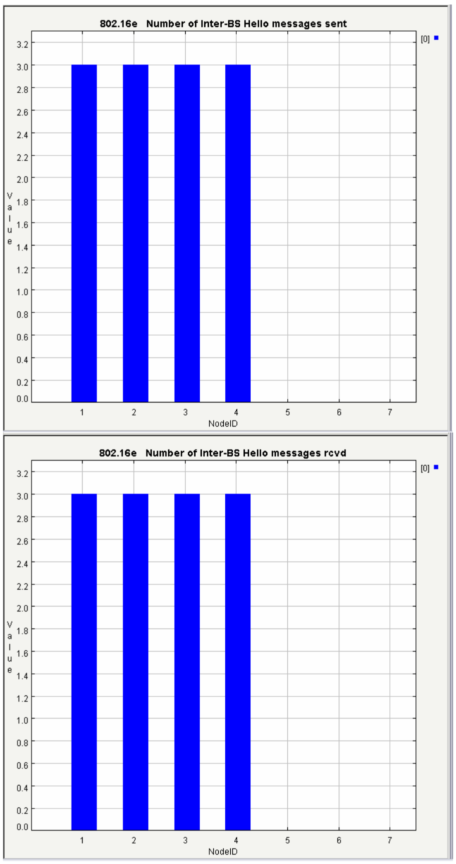

Fig. 7 Inter-BS hello messages

The WiMax handover procedure is divided into two steps: handover preparation and handover execution. During the handover preparation phase, the MS or the serving BS may initiate the handover.

When the mobile node initiates the handover, because this is the case for my simulation scenario, the MS first scans possible target BSs. To do so, it first sends a MOB_SCN-REQ message to its serving BS. This message tells the BS that that the MS is going to perform neighbours scanning. The message specifies a time length for this interval and the type of association it will scan its neighbours with. There are three levels of association:

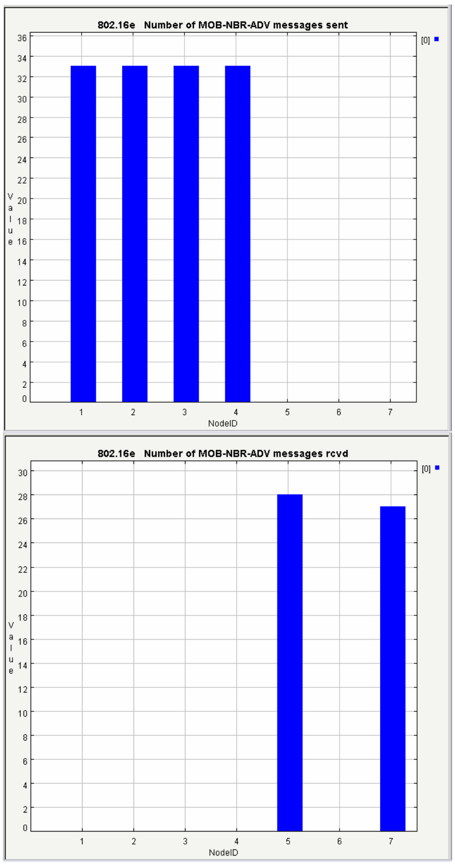

Fig. 8 MOB-NBR-ADV messages

- without coordination – the target BS has no knowledge of approaching MS and the BS allocates periodic intervals where the MS may range neighbour BSs
- with coordination – the serving BS coordinates association with requested target BS's
- network assisted association reporting – similar to previous method, with the exception that the RNG-RSP message is sent over the network backbone to the serving BS. The serving BS puts all the received RNG-RSP messages (from all BS being scanned) in a MOB_ASC_REPORT message and then transmits them to the MS.

The BS will then respond with a MOB_SCN-RSP message, which indicates the length of the approved scan and the association type for the scanning. The MS is now free to scan its neighbours. It can synchronise with a given BS's downlink transmissions and estimate the quality of the physical channel.

The MS shall transmit a MOB_SCN-REP message to report the scanning results to its servicing BS after each scanning period at the time indicated in the MOB_SCN-RSP message. The MS may transmit a MOB_SCN-REP message to report the scanning results to its serving BS at anytime.

The next stage in the HO process is to send a MOB_MSHO-REQ message to the serving BS. This message contains a list of stations the MS recommends as target BSs. The target BSs list is generated after the scanning process. During this simulation, the MS is going to initiate and perform three handovers. On receipt of this message, the serving BS sends a handover pre-notification message to all BS's on that list. It should then receive a handover pre-notification-response from these stations. Using these responses, the serving BS generates a list of target stations, which it sends to the MS in the MOB_BSHO-RSP message.

Upon the receipt of a MOB_BSHO-RSP message, the MS may perform handoff execution. The serving BS is informed via a MOB_HO-IND message. An interesting feature is the fact that the MS may cancel the handover in this message. If it is continuing the handover procedure, it tells the BS that it is leaving that BS and it tells it the parameters of the target BS.

After the MS sends the MOB_HO-IND message to the serving BS, it cuts all communication with serving BS. The mobile node then switches the link and executes ranging with target BS. Also, it negotiates basic capabilities, performs authentication and finally registers with the target BS. Since this time, the target BS starts to serve the MS, it becomes serving BS. Communication with MS via new serving BS is available now.

Figure 9 demonstrates the fact that the IEEE 802.16e offers full mobility and a mobile node is able to perform hard handover. The MS crosses four different coverage areas and performs only three handovers. These results were obtained after the entire network had been optimized. By changing different parameter values the expected results have been obtained.

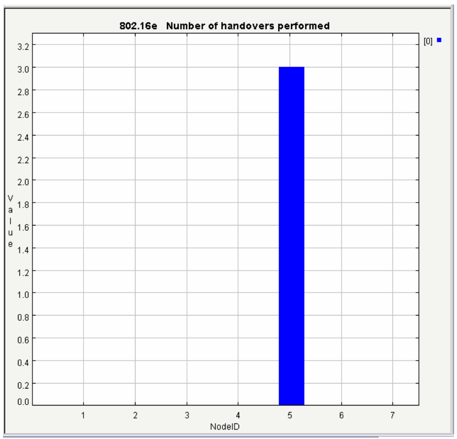

Fig. 9 Number of handovers performed during the simulation

B. *Traffic flow in WiMAX*

To better evaluate the performance of this developed scenario, a CBR traffic flow was generated. As it has been specified, the CBR traffic starts in 6th second of the simulation and ends in the 95th second. The expected results can be checked by running the simulation and analyzing the obtained statistics. The MS sends its first and last packet exactly at the time it was set to do so.

At the destination node (the fixed node), the CBR traffic arrives with a very short delay. The delay for the first packet sent is greater than the one measured for the last packet sent.

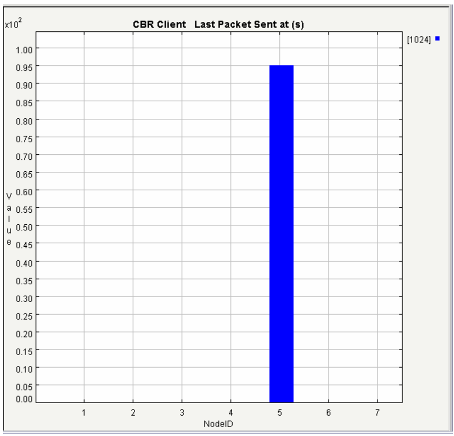

Fig. 10 CBR traffic source

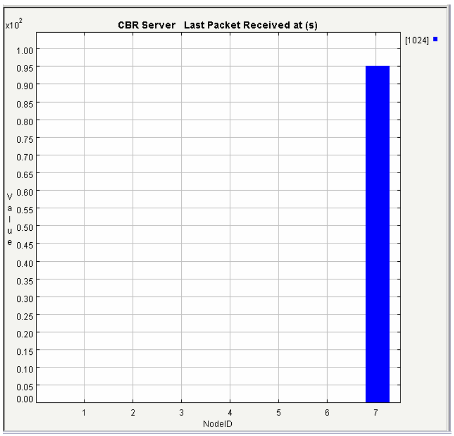

Fig. 11 CBR traffic at the destination (node 7)

Two mandatory QoS parameters for the CBR traffic flows are delay and jitter. Both of them are performance metrics and must be evaluated.

Delay is the time it takes for a packet to reach its destination after it leaves the source node. There are four delay types generated due to transmission, buffering, scheduling and retransmission. For o better understanding of this parameter, some notations have been made. Dq includes all types of delay (buffering, scheduling, retransmission) except transmission delay (Dt). It is very important to know that maxD and data rate are not independent and also Dt is proportional to data rate. The total delay introduced in the system can be calculated as $D = Dq + Dt$. As it can be seen in the figure 12, the total average delay introduced is 49ms. This obtained value is within tolerable limits for a CBR traffic flow because the specified theoretical limit is 100ms for this kind of traffic flow.

Other important QoS parameter that must be evaluated is the jitter. Jitter is defined as the difference between the expected packet arrival time and the measured packet arrival time. In networks, jitter for an application, normally, can be defined asJ maxD − minD. During the simulated scenario, the average jitter is around 11ms. This value is also within tolerable limits.

V. REMARKS

Based on the simulation results the following observations can be made:

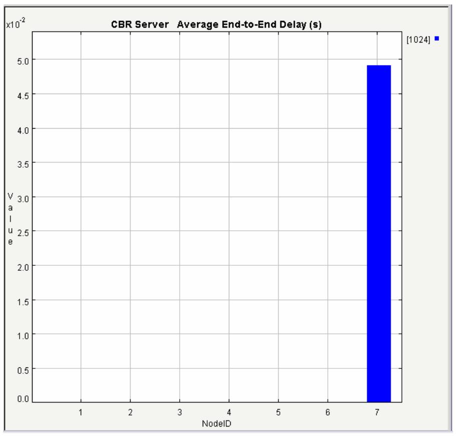

Fig. 12 The average end-to-end delay

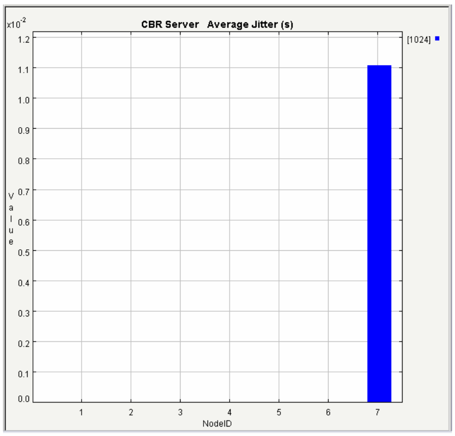

Fig. 13 The average jitter

- the average delay and the average jitter are within tolerable limits
- there is no packet loss rate (adequate buffering at the SS and the BS)

An important thing to take into account is the average delay that increases with the increase in number of active sessions. In order to maintain the delay within tolerable limits, rate control mechanisms must be implemented at the BS or the queue size at the BS must be increased. Also, as soon as the system gets overloaded there is a sharp increase in the average delay (the number of MSs introduced in the scenario is increased).

The results show that the performance of the system, in terms of jitter and delay, depends on several factors: frame duration, traffic type, network load, scanning interval, channel bandwidth, number of used subcarriers etc.

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