Performance Evaluation of a WiMAX Network Using Smart Antennas Through System in the Loop OPNET Simulations

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***Abstract*—Worldwide Interoperability for Microwave Access (WiMAX) is one of the newest technologies developed for broadband wireless networks, which offers high data rate and high flexibility for the radio resource management. Adding smart antenna support and developing new scheduling algorithms will make WiMAX an attractive solution for the next generation wireless networks. In this paper, a basic simulation testbed for performance evaluation of a WiMAX network using smart antenna is proposed. It is based on OPNET simulation tool and uses System-in-the-Loop function to interconnect the simulated system with a real network, for a better functional and performance evaluation. The simulation results showed that the higher antenna gain on the beam direction and the narrow beam will result in a reduced level of interference and a higher throughput in the WiMAX network.**

Keywords - WiMAX networks; smart antenna; OPNET; System-in-the-Loop.

I. INTRODUCTION

The IEEE 802.16 technology and WiMAX-based systems constitute an attractive solution for metropolitan and rural areas [1]. It offers high capacity links, and based on the relay technology introduced in 802.16 j standard it can also provide high coverage too. Scheduling the radio resources in a relay based topology is a very challenging task. To cope with interference issues in such topologies, directional smart antennas can be introduced to obtain increase in performance, while keeping the transmitting power at the same level as for omnidirectional antennas case.

In this paper, the performance of a WiMAX network, which uses smart antennas at the Base Station and Subscriber Station, is evaluated. A basic testbed was built for this purpose. It is based on OPNET simulator and uses the System-in-the-Loop function to interconnect the simulated system with a real network, for a better functional and performance evaluation [2][3]. The testbed was developed in the framework of the SMART-Net FP7 project, which aimed to investigate the use of smart antennas in Wireless Mesh Networks mainly based on WiMAX and WiFi technologies. The project proposed efficient scheduling algorithms, to enhance the capacity and to provide scalability, reliability and robustness for such a system [2][4]. Inside this project, performances evaluation based on both simulation and real life experimental platform has been conducted. In order to increase the accuracy of the evaluation platform, the cooperation between the simulated network and the real life platform has been achieved by coupling them using the System- in-the-loop OPNET function. This paper presents the experimental results for evaluating the smart antennas integration on standard OPNET WiMAX nodes [5].

This paper is organized as follows. The second section is a short description of the SMART-Net system and of the smart antennas. The third section is dedicated to the testbed structure and the simulation scenarios. The fourth section provides the simulation results. The last section presents conclusions and guidelines for future work.

II. SMART-NET SYSTEM

A. *Smart-Net features*

Smart-Net solution for Broadband Wireless Access is based on multimode devices with smart antennas support. These devices are interconnected in a partial mesh topology, which has a central point, Smart Gateway (SMG), acting as a gateway linked to the backhaul networks. The other nodes of the network are either SMART Stations (SMS) or SMART Relays (SMR). A SMR is an operator’s equipment, which is specifically used to forward data traffic to the users, allowing coverage extension and cooperative diversity, while a SMS is a subscriber station, that also enables data transfer for other users based on the service provider policy [1] [4].

Using omnidirectional antennas in wireless networks create inherently interference, which decrease the capacity of the system. A significant capacity increase could be obtained by using smart antennas. They feature a directivity that can be controlled by higher levels protocols (Layer 2, Layer 3) in the network node, allowing its orientation towards the destination node, and thus reducing interference.

ISBN: 978-1-61208-199-1

The Smart-Net project introduced smart-antenna support on WiMAX equipments and developed some algorithms for scheduling and routing in a multihop relay based WiMAX mesh network [4][6][7][8]. To validate the proposed solutions two testbeds were developed during the project [5]. First is a real life testbed consisting of WiMAX equipments with smart antennas. The WiMAX equipments used in the testbed are produced by Thales Company and the smart antennas are produced by Plasma Antennas Company. Both are members of the Smart-Net project. The second is a simulation platform, which was developed using the OPNET network simulator. The smart antennas were modeled in the OPNET and integrated with the simulated WiMAX nodes. Also, it was proposed by the project to combine the real life and simulated testbeds to obtain more significant results of the proposed system's performances. For the testbeds interconnection the System-in-the-Loop (SITL) function provided by OPNET was used. Such approach is presented in [9], where SITL is used to evaluate WiFi wireless networks performances. In this paper a similar approach is used to evaluate the smart antennas integration on the WiMAX nodes and the smart antennas performances.

B. *Smart antennas*

Smart antennas are systems, which intelligently combine multiple antenna elements with signal-processing capability to optimize its radiation and reception patterns automatically [4]. They have a certain number of fixed high gain beams with low sidelobes, which minimize interference both on transmit and receive, without using complex adaptive nulling algorithms. Low sidelobe multi-beam antennas have the advantage over adaptive systems in that they suppress a very large number of interferers in a consistent, predictable way. Adaptive antennas systems are limited by their degrees of freedom (e.g., number of radios), their adaptation time and might not work well when the signal of interest is at the edge of the receiver's sensitivity. However, they potentially have the advantage of allowing the suppression of interfering signals that are close in angle (within a beamwidth) to the source-of-interest. When receiving, the adaptive smart antennas can maximize the sensitivity in the direction of the desired signal and minimize the sensitivity towards interfering sources.

For reasons of cost and consistency of performance, common smart antennas are switched or selectable multi-beam antennas, requiring only a single radio. These antennas have multiple fixed beams, and the system switches very rapidly between these beams.

For the SMART-Net project, two types of switched multi-beam antennas, capable of WiMAX operation, have been designed and implemented [2] [4].

- An active, 12 beam cylindrical array antenna with omni-mode
- A passive 9 beam planar array antenna with sectoral mode.

The active 12-beam cylindrical antenna with 360° coverage has been selected to be most suitable for mesh and nomadic Point to Multipoint operation. It has typical ranges of up to 20 km, depending on the modulation rate. The passive 9 beam planar antenna, with its narrow beams, has been selected to be most suitable for medium range backhaul and relay operations. A representation of both antennas, suitable for inclusion within OPNET, has also been provided, but as simulated data.

Besides the multibeam antennas, a switching algorithm is used to choose the appropriate beam among the available antenna beams. This algorithm is based on a learning interval in which, based on SINR, the best beam is chosen for each destination. Based on the decision took by the selection algorithm, when a smart node (a node equipped with smart antennas) needs to communicate with another smart node, the beam with the best SINR is used. Because the best beam is decided in the learning phase, the switch operation is very fast, a few nanoseconds. Some performance degradation is expected in the mobile nodes case, because the learning interval lasts a few milliseconds. In this paper, only evaluation of smart antenna on fixed WiMAX nodes is presented. For mobile nodes, the smart antenna integration is not ready.

III. SIMULATION INFRASTRUCTURE AND SCENARIOS FOR SMART ANTENNAS

A. *Simulated testbed infrastructure*

The testbed infrastructure consists of a simulated WiMAX network, which is interconnected with real devices in order to introduce real time traffic in the simulation (Figure 1). The System-in-the-Loop is an OPNET facility, which allows real time communication between real and simulated parts of the network [2][8][10]. By using SITL, OPNET simulation exchanges the packets between simulations and real networks in real-time. The SITL gateway represents an external device through which the simulation exchanges the packets; the WinPcap library is used to route those packets selected by user defined filter, from an Ethernet network adaptor, to the simulation process. The real time requirements are introducing hard constraints on the simulation platform's hardware.

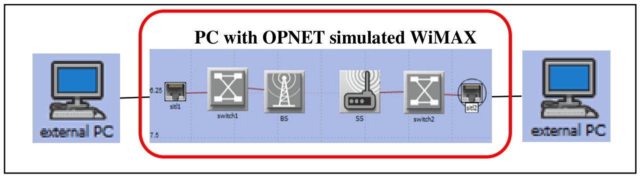


Figure 1. Simulated testbed infrastructure.

The simulation runs in real-time and exchanges packets with the external hardware via an Ethernet link. The requirement of using Ethernet link between the real devices and the SITL gateway introduces limitation in developing joint real and simulated wireless network scenarios. Joint scenarios for evaluating scheduling and routing algorithms for wireless mesh networks are not possible with SITL.

B. *Scenarios for smart antenna performance evaluation*

The basic topology of the simulated WiMAX network used for evaluation of smart antennas performances is

ISBN: 978-1-61208-199-1

presented in Figure 1. A real-to-real SITL topology is used for these scenarios. It consists of a single WiMAX link, between a Base Station and a fixed Subscriber Station, which is concatenated with Ethernet links at both ends. These Ethernet links are used to interconnect, via SITL gateways, the WiMAX simulated network with the external stations, which are both acting as real time streaming server and player. The smart antennas were installed on the simulated WiMAX nodes. Introducing smart antenna support on standard WiMAX nodes requires modifying the radio transceiver pipeline stages. The beam selection algorithm was introduced in the pipeline stages together with the 12 beam cylindrical array and 9 beam planar array antenna models.

The following two scenarios were created in order to evaluate the smart antennas integration in standard WiMAX nodes using the OPNET SITL tool. The first one uses the topology given in Figure 1, which consists of a single WiMAX link. Both BS and SS are equipped with standard WiMAX nodes (with omnidirectional antennas) initially. The capacity of a standard WiMAX link is determined. In a second phase, the omnidirectional antennas are replaced with smart antennas. The scenario is run again to determine the capacity of the WiMAX link for smart antenna case. The second scenario aimed to determine the interference level in a WiMAX network when the smart antennas are used taken as reference the interference generated by omnidirectional antennas. For this purpose, near the WiMAX link, used to carry the real time traffic, a small WiMAX network (one Base Station- BS, with several Subscriber Stations- SS) is placed. The nodes of this network are used to generate interference on the main WiMAX link. The scenario is run with both omni and smart antennas installed on the nodes used to generate interference.

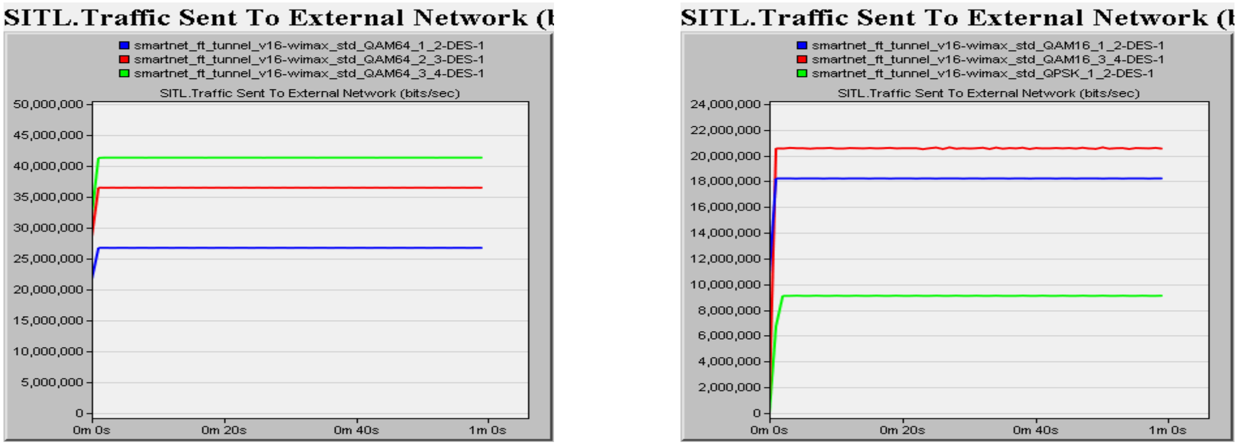
IV. SIMULATION RESULTS FOR SMART ANTENNA PERFORMANCE EVALUATION

A. *Simulation components and parameters*

In this section, the smart antennas performance evaluation results obtained using the simulation testbed will be presented. The simulation platform consists from the following components as shown in Figure 1: two PCs used one as real traffic generator and the second as player; a third PC, with OPNET installed, is used to simulate the WiMAX network. The PC with OPNET must be a performant one in order to run the simulations in real time. The hardware simulation platform used for the experiments is based on Intel XEON-quad core processor, running at 2.66GHz, with 6GB RAM. Windows 7 and OPNET version 16 software are installed on it. Two 1GB Ethernet cards are used to interconnect the simulation PC with the external PCs. In the first scenario a direct WiMAX link, between a Base Station and a Subscriber Station, is simulated in OPNET. Both WiMAX nodes are standard nodes equipped with omnidirectional or smart antennas. The WiMAX physical parameters are: 20MHz bandwidth, 2048 subcarriers, 10.94 kHz subcarrier frequency spacing, symbol duration of 102.86μs, frame duration of 5ms. The antenna gain is set at 15 dB and the receiver sensitivity was set at -100dB.

A first test suite aimed to evaluate if there are any limitations introduced by the SITL interface in the WiMAX performances. For this purpose, the free space propagation model was chosen, multipath channel model was disabled, and the distance between BS and SS was set at around 200m. With these parameters for the radio channel, the transmission is done in very good conditions. The Iperf application was used to generate UDP traffic at a rate of 50 Mbps. Several modulations and coding rates were configured for WiMAX physical layer: QAM64 3/4, 2/3, 1/2; QAM 16 3/4 and 1/2. The data throughput obtained on the output SITL interface for different modulations and coding rates are presented in Figure 2. The data throughput through the WiMAX link, measured at the output of the simulated network and at the destination PC, reaches the maximum link capacity for the given WiMAX parameters. The obtained results show that the SITL interfaces and the real-time constraints imposed to the simulation does not affect the network performances.

As can be seen from Figure 2, the throughputs obtained through the WiMAX link in each case are closed to the values indicated by the standard.



a) b)

Figure 2. Data throughput obtained on the output SITL interface for:a) QAM 64 modulation 1/2, 2/3, 3/4 b) QAM16 1/2, 3/4 and QPSK 1/2

B. *Basic evaluation of link capacity for WiMAX nodes equipped smart antennas*

In this scenario, a movie with a rate around 2.5 Mbps is streamed from the streaming server through the simulated WiMAX link. On the same link and in the same direction (downlink) it is transmitted a noise UDP traffic with the rate of 5Mbps. All the flows are transmitted as Best Effort. A total of around 7.5 Mbps throughput is transmitted on the downlink. The WiMAX physical parameters are: 20MHz bandwidth, 2048 subcarriers, 10.94 kHz subcarrier frequency spacing, symbol duration of 102.86 μs, frame duration of 5ms. The antenna gain is set at 15 dB. QPSK 1/2 modulation and coding scheme were selected, and the planar 9 multibeam smart antennas were installed on WiMAX nodes.

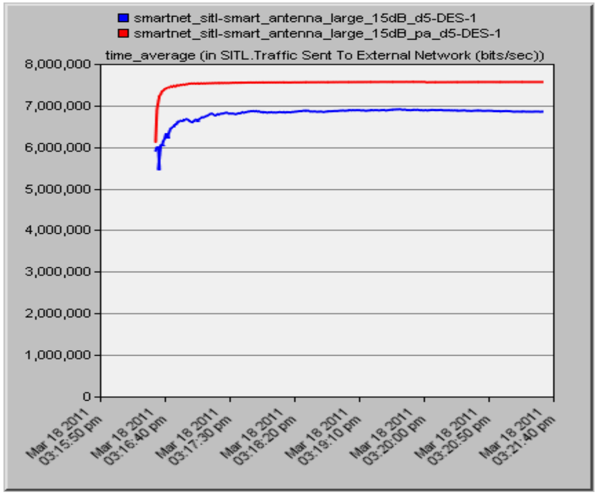


Figure 3. Wimax throughput – omni beam and smart-antenna; blue – omnidirectional antenna; red – smart antenna

Both the omni and smart antennas scenarios were repeated by varying the distance between the BS and SS. As it was expected the capacity of the WiMAX link decreases while the distance between nodes is increased. The Wimax capacity decrease is illustrated also by the perceptual evaluation of the movie quality and by the throughput statistics measured on the WiMAX link. In all experiments performed, the WiMAX link capacity was similar or better than in case of omnidirectional antenna as is illustrated in the Figures 3. It presents the throughput obtained in the omni-beam and smart antenna case when the BS and SS are at the same distance and in the same positions. The higher throughput curve corresponds to the smart antenna scenario. For small distances between the BS and SS node the throughput is the same. When the distance is increased the difference between the throughputs obtained in each case is increased – the higher throughput being obtained when using smart antennas. A perceptual evaluation was performed using the real time movie, which was sent through the simulated networks together with the UDP noise traffic. By subjectively observing the movie quality at the output of the simulator, it was compared the WiMAX network behavior in the omnidirectional and smart antennas cases. In all the scenarios, the movie quality was the same or better for the case when the smart antennas were used on WiMAX nodes compared with the case of omnidirectional antennas usage on WiMAX nodes.

C. *Interference evaluation for omni and smart antennas cases*

A second scenario was built to evaluate the interference level in a WiMAX network with nodes equipped with smart antennas, and to compare it with the interference generated by WiMAX nodes equipped with omnidirectional antennas. In order to evaluate the interference level, near the WiMAX link from the previous scenarios was placed a small WiMAX network with one BS and several subscribers. This second network is used to generate interference on the link, which is used to send the real time traffic flows.

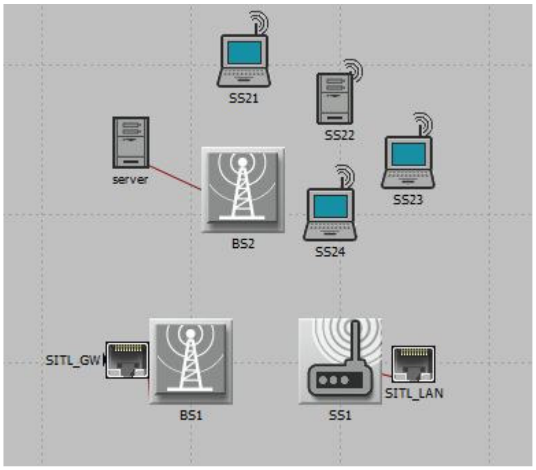


Figure 4. Interference evaluation scenario topology

The scenario is run both with the interference network enabled and disabled. The behavior of the main WiMAX link is evaluated for both cases: with and without interference. The same experiment is repeated for WiMAX nodes equipped with smart antennas. With this scenario, the interference generated by a WiMAX network with omni or smart antenna equipped nodes can be evaluated at a node level from the SNR statistics. The expected result is that the interference amount will be smaller when smart antennas are used by the WiMAX nodes.

The scenario topology is shown in Figure 4. The interference network consists from the server node, BS2 node, and the SS21, SS22, SS23, SS24 nodes. Local video traffic is generated between the interference nodes. The real time traffic is generated with Iperf application at a rate of 20 Mbps. For the WiMAX channel the ITU Pedestrian A multipath channel model and Pedestrian A pathloss model were selected. The other WiMAX parameters are identical with the ones used previous scenarios.

First experiments are performed using nodes equipped with omnidirectional antennas. The same experiment is run initially with the nodes, which generate interference, disabled, and then with all the nodes enabled.

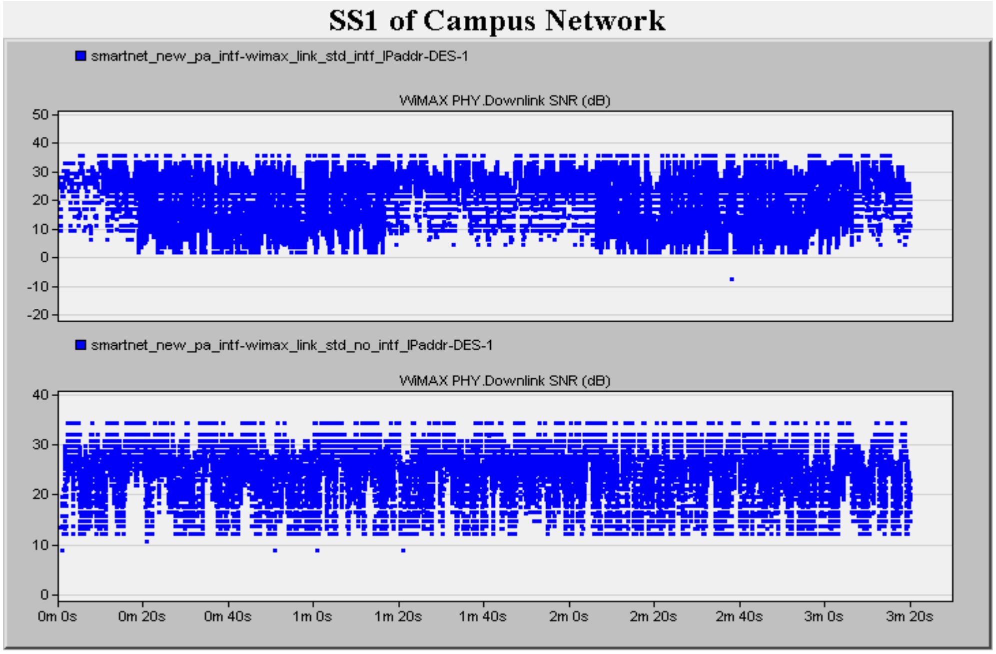


Figure 5. Downlink SINR values for the signal received by the SS1 node: **up-** interference nodes enabled; **down-** interference nodes disabled

The results are shown in the Figures 5, 6 and 7. In these figures, the downlink SNR measured at the SS1 station and the traffic sent in the interference network are presented. One can see that, when there is traffic in the interference network (Figure 6), the SNR level measured by the SS1 on the affected link is decreasing with almost 10 dB (Figure 5). This is caused by the radio signals coming from the interference WiMAX network. In Figure 7 the packets lost statistic measured at a node, SS21, in the second WiMAX network is shown. The packets lost is caused by the interference, which is generated by the WiMAX nodes BS1 and SS1 while transmitting the real time traffic. One can see that a lot of packets are lost because of the SNR degradation.

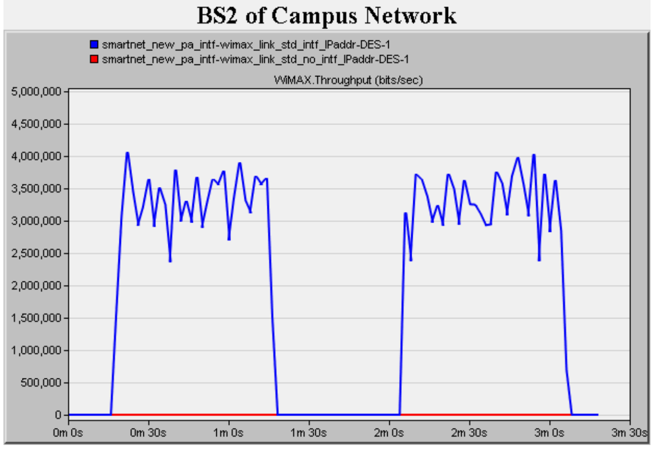


Figure 6. The throughput at the BS2 node –traffic generating interference at SS1 node

In both Figures 6 and 7, the blue curve corresponds to the results obtained when the nodes, which generate interference, are enabled, while the red curved illustrates the statistics obtained when the interference generating nodes are disabled.

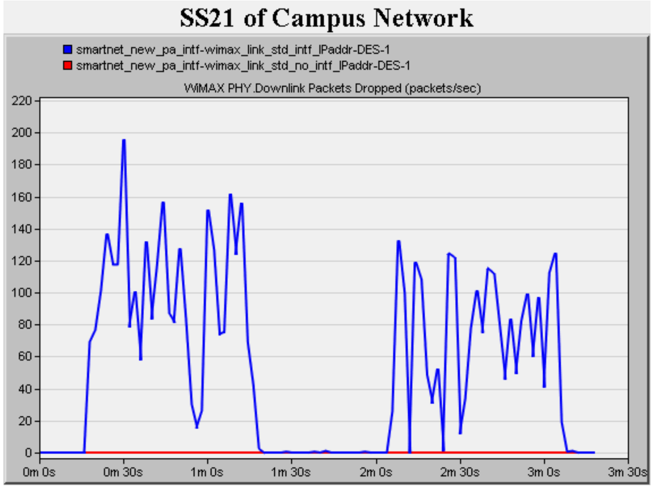


Figure 7. Packets lost at SS21 node – caused by the interference generated by the BS1-SS1 WiMAX link

A second test suite is done using nodes equipped with smart antennas. The topology and all other parameters were kept unchanged. A similar traffic pattern was used for this test suite. Local video traffic was generated between the interference nodes, and real time traffic was generated with *Iperf* application at a rate of 20 Mbps. The first experiment was played with the interference network activated. The

SNR measured at SS1 node, when the interference nodes are enabled, is shown in Figure 8. The SNR is similar with the SNR measured by SS1 when the nodes are equipped with omnidirectional antennas and the interference nodes are disabled. This shows that the level of the interference signals is low when smart antennas are used. Also, one can see that, the higher values of the SNR, in the scenario with nodes equipped with smart antennas, are with more than 10 dB greater than the SNR in the scenario with omnidirectional antennas. This is a consequence of the narrow beams used by the SS1 and BS1 antennas, which cause a smaller amount of interference due to multipath propagation.

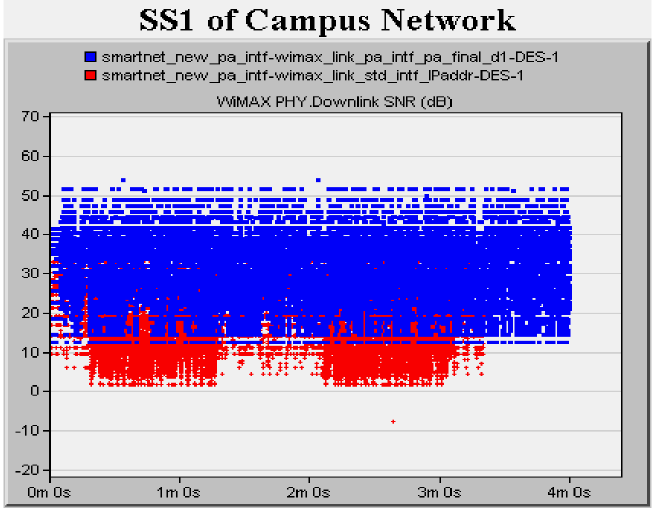


Figure 8. Downlink SNR at SS1 node - interference network enabled rede – omnidirectional antenna; blue – smart antenna

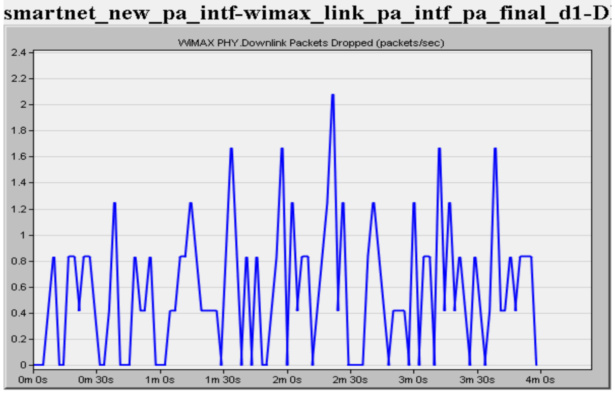


Figure 9. The number of downlink packets dropped at SS1 node

In Figure 9, the packet lost statistic for the node SS1 is presented when the interference network is enabled. There is a mean of less than one packet/s loss, which is much better than the loss obtained when the omnidirectional antennas are used. All these results demonstrate that using directional smart antennas on WiMAX nodes one can increase the capacity and coverage of the network. Because the beam switching is very fast, a few nanoseconds order, these smart antennas can be used at both Base Station and Subscriber Station for fixed and nomadic scenarios.

V. CONCLUSION AND FUTURE WORKS

This paper presents an evaluation, using the OPNET simulator, of a basic WiMAX network with nodes equipped with smart antennas. It presents basic scenarios and experiments for evaluation of smart antennas integration on WiMAX nodes and the obtained performances. The simulations results presented in this paper illustrate that, for fixed WiMAX nodes, the usage of the proposed smart antennas will bring a significant performance gain, expressed in terms of capacity and coverage. Because of the fast beam switching, these smart antennas can be used successfully in fixed scenarios. The smart antenna behavior on mobile WiMAX nodes is a subject of further research. The main issue for mobility is to develop a tracking algorithm capable of detecting in real time the best beam to be used to reach the mobile node.

ACKNOWLEDGMENT

This work was supported by the EU FP7 project SMART-Net, no 223937, by the Romanian UEFISCSU PN-2 RU-TE Project no. 18/12.08.2010 and by the EU and Romanian Govern EXCEL project - POSDRU/89/1.5/S/62557.

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