A wireless mesh network solution based on WiMAX technology with smart antennas support

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***Abstract*—Wireless Mesh Networks represent a good solution to offer Internet access in sparse population areas. The latest wireless technologies, such as WiMAX, offer high data rates services, but they are not designed for wireless mesh architectures. This paper proposes a wireless mesh solution based on WiMAX nodes equipped with smart antennas, and presents some tests for performance evaluation of the proposed solution. The WiMAX mesh node is emulated by interconnecting, via Ethernet, a Base Station and a Subscriber Station. To avoid interference between the two radio interfaces, they are configured to operate on different frequency bands. The WiMAX mesh node is simulated in OPNET and its performance is compared with a real life implementation of such a hybrid mesh node. The performance evaluation was done using an experimental platform, consisting of both a simulated and a real life part, which are interconnected through the System in the Loop OPNET function.**

Keywords-mesh network; WiMAX; Smart Antennas; OPNET simulator; System in the Loop.

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) was developed for broadband wireless networks, and it offers high data rate over long distances [1]. An application suitable for WiMAX technology is its usage in wireless backhaul networks, to provide coverage over low density areas or as alternative solutions to wired networks. Such a solution offers resilience in disaster scenarios obtained through self healing property facilitated by the wireless communication. [2].

Wireless Mesh Networks are the solution for wireless backhaul (WMN). On one side, the WMNs share common features with ad hoc networks (MANET), on the other side, the WMNs, being used for backbone, have minimal mobility and no constraint on power consumption. The WMN routing protocols can be generally adapted from those used in fixed networks and also from ad hoc networks, but, due to the specific conditions of WMN routers (limited mobility and no power constraints), the protocols like in fixed networks can be more appropriate.

The work presented in this paper was done 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 technology. A solution for WiMAX mesh networks based on hybrid WiMAX mesh nodes is investigated. This hybrid node was obtained by linking a Base Station with a Subscriber Station via Ethernet. Both stations include layer three capabilities, mainly routing capabilities. A node with relay properties is obtained, which has also routing capabilities. This solution was implemented and simulated in the OPNET simulator. A similar approach was developed by Thales Company for the real implementation of such a hybrid node [3]. Here, the Subscriber Station functionalities were implemented on a Base Station platform. Special timing synchronization between the uplink and downlink intervals for Base Station and Subscriber Station was introduced, in order to avoid interference between the two wireless interfaces, by not allowing them to transmit and receive simultaneously.

There are several works on wireless mesh networks based on WiMAX, but they focus on multihop relay networks built with WiMAX relay stations, built based on the IEEE 802.16j [1]. A spanning tree rooted at Base Station is built, with Subscriber Stations as leaf nodes. Usually, these works approach scheduling and channel assignment algorithms to optimize the resource allocation in multihop relay networks [4][5]. There are also approaches which consider multihop relay networks with smart antenna support, and which try to find solutions for joint resource allocation and beam scheduling in order to reduce the interference and increase the overall throughput [6][7]. Most of the proposed algorithms are based on centralized solutions. In this paper, due to the way the WiMAX mesh node is build, the solution is completely distributed, without any correlation between the scheduling or channel assignment at each node.

This paper is organized as follows. The second section is dedicated to Smart-Net system presentation. The third section presents the experimental platform setup, while the fourth section presents the test scenarios and the results. The last section contains the conclusions and some suggestions for future work.

II. SMART-NET SYSTEM COMPONETS

A. *SMART-Net system*

As it was mentioned in the previous section, this solution was proposed in the SMART-Net project, which focused on introducing the smart antennas support in WiMAX technology and on developing a wireless mesh network for backhaul access, based on WiMAX nodes with multiple radio interfaces. To validate it, an experimental platform was developed during the project [8]. This test platform consists of a simulated part and a part realized with real WiMAX nodes, equipped with smart antennas. The WiMAX equipments used in the testbed are produced by Thales Company, while the smart antennas are produced by Plasma Antennas Company. Both are members of the Smart-Net project. The simulation platform was developed using the OPNET network simulator. The smart antennas were modeled in the OPNET, based on the real antennas measurement data, and integrated with the simulated WiMAX nodes. Also, the beam selection and tracking algorithms were implemented in OPNET and included in the WiMAX radio pipeline stages for the Smart Antennas control. The interconnection of the two test platform components was realized using the System-in-the-Loop (SITL) function provided by OPNET. The real part was developed at France Telecom premises located in Lannion, France, while the simulated part was developed at University Politehnica of Bucharest (UPB) in Romania. The two testbeds were interconnected through a VPN tunnel via GEANT network. The interconnection setup is illustrated in Fig. 1. With such an approach, the capability of the proposed backhaul network to operate over large areas was tried to be proved.

Some initial results of this work are presented in [9]. There, only the simulated network was evaluated. In this paper, both simulated and real network were integrated in an experimental platform. A similar approach is presented in [10], where SITL is used to evaluate WiFi wireless networks performances with real time traffic injected in the simulated network.

B. *Smart Antenna features*

One of the main topics of SMART-Net project was the introduction of smart antenna support in WiMAX. Smart antennas define antennas which are capable of adapting the radiation and reception pattern automatically. They provide a higher gain on the main beam direction and much smaller gains on the secondary beams, which will ensure a lower interference noise.

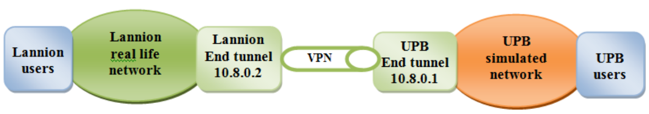

Figure 1. Testbeds interconnection setup

In practice, one can have two types of smart antennas. One is represented by adaptive smart antennas, which are capable of adapting its beam in every direction, by adaptively combining the signal from multiple antenna elements. They have the advantage of being able to adapt the beam in every direction, but with the drawback of higher switch time and increased complexity. The second type is represented by switched beam antennas, which has several fixed beams and can be selected individually. They have only a limited number of directions which can be obtained, but they are rapid and with a simpler implementation.

For the SMART-Net project, two types of switched multi-beam antennas, capable of WiMAX operation, have been designed and implemented [3] [11]. An active, 12 beam cylindrical array antenna with omnimode and a passive 9 beam planar array antenna with sectoral mode. The active 12-beam cylindrical antenna with 360° coverage is 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, has narrower beams, and is suited for medium range backhaul and relay operations. A representation of both antennas in OPNET has also been provided as simulated data.

A switching algorithm is used to choose the appropriate beam. 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 taken 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.

III. EXPERIMENTAL PLATFORM SETUP

The experimental platform infrastructure consists of a simulated WiMAX network, which is interconnected with real devices in order to introduce real time traffic in the simulation, Fig.1.

The System-in-the-Loop OPNET function allows real time traffic to be exchanged between real and simulated parts of the networks during the simulation. The actual OPNET version works only with an Ethernet network adaptor for SITL interconnection. 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. For the SITL scenarios, the simulation must run in real-time. This requirement introduces an additional limitation for the SITL scenarios: it limits the number of nodes, which can be used in the simulation.

A. *Real Life testbed infrastructure*

The Real Life testbed was developed at the France Telecom Lannion premises. Its structure is presented in Fig. 2. Its main part consists of a WiMAX network with one Base Station, three Subscriber Stations and one Relay Station. The Relay Station [3] is built by combining a Subscriber Station and a Base Station together and synchronizing them in terms of uplink and downlink mapping: the scheduling for the uplink and downlink transmission intervals for both WiMAX links, given by the UL and DL MAP fields from the WiMAX frame generated by the main Base Station and the Relay Base Station, must be synchronized in order to reduce the interference at the relay node.

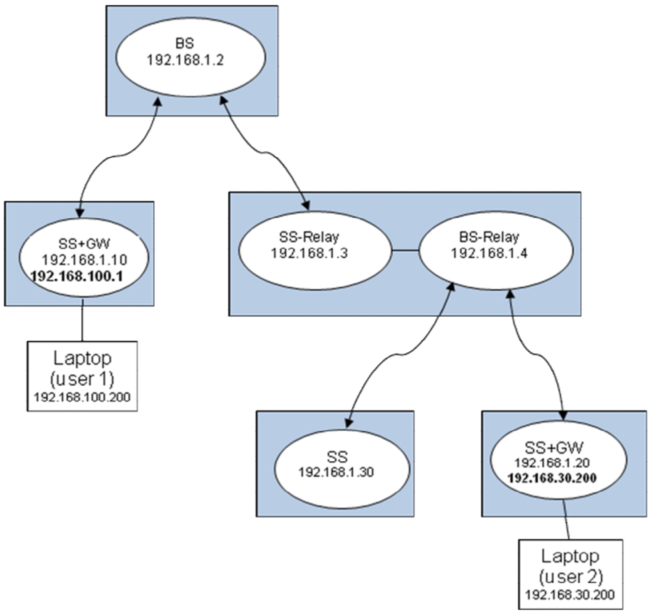

Figure 2. The real life testbed infrastructure

The WiMAX nodes were equipped with two antennas: the smart antenna having a beam gain of 16.5 dBi (beam mode) / 12.5 dBi (omni mode) and, for comparison reasons, a classic sector antenna of 17 dBi. They worked in the 5470 - 5725 MHz band at constant Equivalent Isotropic Radiated Power (EIRP) of 30 dBm. Consequently, the transmission power of the base station was set to 24 dBm and those of the subscriber node to 14 dBm (smart antenna beam mode) or 18 dBm (smart antenna sector mode). More details about the performance of the Lannion real life WiMAX network can be viewed in [12][13].

The WiMAX BS is connected with the Lannion Internet gateway. This gateway is used to host the VPN client which in used to connect to the VPN server located at UPB premises. The VPN tunnel is a layer 3 tunnel. From a logical point of view the Lannion test bed consists of a direct WiMAX link (a BS-SS link) and a relay based link (BS-SS_relay-BS_relay-SS) – Fig. 2. A stream flowing through the real life testbed will cross one or two WiMAX links, depending where it generates/ends (user 1 or user 2).

B. *Simulation testbed infrastructure*

For the simulated network the main WiMAX physical parameters are: 20MHz bandwidth, 2048 subcarriers, 10.94 kHz subcarrier frequency spacing, symbol duration of 102,86 ms, frame duration of 5ms [9]. Adaptive modulation and coding is configured on the subscriber stations. Receiver sensitivity is set to -100 dB for both the SS and BS stations.

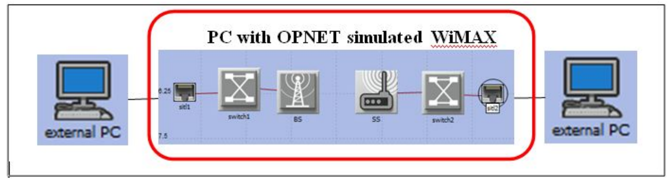

Figure 3. Simulated testbed infrastructure

As shown in Fig. 3, our approach is based on the real-to-real SITL interconnection scenario. Real packets are injected in the simulated network through the SITL interface, flows through the simulated network, are sent outside the simulation through another SITL interface, and are received on a real device. In this way, we can measure the effects of the simulated network on the real packets, obtaining a more accurate evaluation tool for the proposed solutions. The results presented in this paper are obtained by using the following configurations for the simulated network: direct WiMAX links interconnecting the SITL gateways or a double WiMAX link obtained by interconnecting the Base Station with the Subscriber Station through a hybrid mesh node, similar with the relay node used in the real life testbed for the relay based link. As already mentioned, the simulated hybrid mesh node (relay node) was obtained by linking a WiMAX Base Station with a Subscriber Station via Ethernet. The performance of this simulated hybrid mesh node was compared with that of the real hybrid relay node implemented by Thales Company.

IV. TESTS SCENARIOS AND RESULTS

In this section, the test scenarios, used to evaluate the hybrid node performance, and the test results are presented. For these tests, all the real nodes are equipped with smart antennas; while for the simulated nodes both standard and smart antennas were used. The benefits of using smart antennas on WiMAX nodes in static or nomadic configurations are also shown. A first set of experiments was used to evaluate the delay and jitter introduced by the hybrid node, the real one and the simulated one also. A second set of experiments was used to evaluate the performances of the implemented WiMAX network when the smart antennas were used on the WiMAX nodes.

A. *Delay and jitter evaluation for the WiMAX network based on hybrid node*

The tests performed focused on delay and jitter estimation for different segments of the end to end link between Lannion users and UPB users. Round trip time (RTT) value was determined using the ICMP protocol to estimate the delay. The jitter was evaluated using *iperf* application. Standard *iperf* algorithm was used to calculate the jitter. In the experiments presented in this paper only passive 9 beam planar array antennas with sectoral mode were used for smart antennas.

For the RTT and jitter figures, the time in milliseconds is represented on the y-axis, and the packet number on the x-axis. For figures obtained with OPNET simulator, on x-axis the time in minutes is represented.

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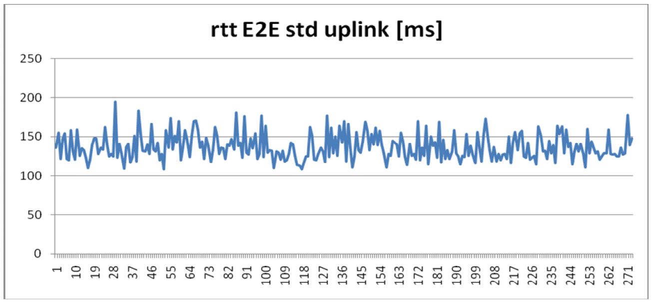

Figure 4. The end to end RTT for standard antennas on the simulated nodes

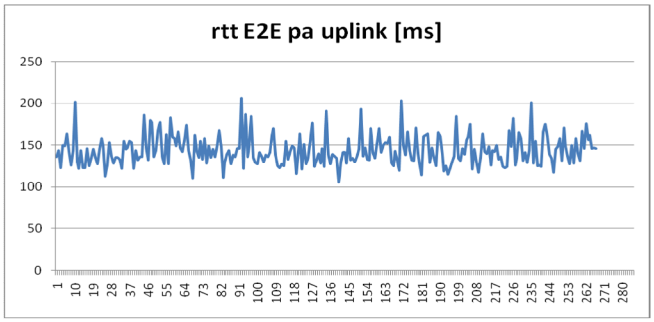

Figure 5. The end to end RTT for plasma antennas on the simulated nodes

The tests were performed for both the standard antennas and smart planar antennas on WiMAX nodes. For the simulated WiMAX link, adaptive modulation and coding was used, and best effort service flows were considered for uplink and downlink.

A first test suite was performed using one WiMAX link in the simulated network and one WiMAX link in the real network. To evaluate the round trip time *ICMP* packets were sent from UPB laptops situated behind the simulated networks. The packets traveled via the simulated WiMAX link, through the VPN tunnel, via the real WiMAX link and then the way back. The RTT obtained for the cases when the simulated nodes were equipped with standard and smart planar antennas were presented in Fig. 4 and Fig. 5. As it was expected the results are similar. One can see that the mean RTT was around 150ms. This value for mean RTT was obtained by taking values for long time intervals.

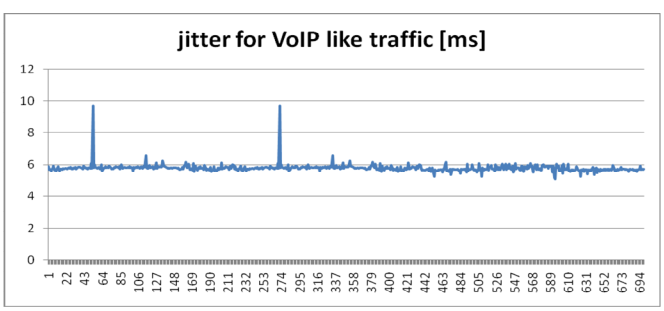

Figure 6. End to end jitter from Lannion to UPB for emulated VoIP traffic

To evaluate the interconnected testbeds behavior for VoIP communications, traffic emulating four VoIP channels was generated using the *iperf* application. The data rate used was of 320 kbps and the packet size was set to 120Bytes. The jitter measured with *iperf* is shown in Fig. 6. The jitter value is around 6 ms which is acceptable for VoIP communications.

The jitter was measured also by sending with *iperf* a 5Mbps UDP data stream from Lannion to UPB. The packet size was set in this case to 512Bytes. In this case the mean jitter was about 5ms.

In order to determine the components of the RTT delay, the individual RTT delays for the links that make up the end to end path were evaluated. The results are presented in Fig.7, Fig. 8, and Fig. 9. The RTT mean delay of the simulated WiMAX link is around 45ms, while the RTT delay for real WiMAX link is around 35 ms. For the simulated WiMAX network the RTT variance is very high because of the variable time it takes for a packet to be translated to the simulation and back. Also, the extra delay for the simulated network is given by the packet conversion time.

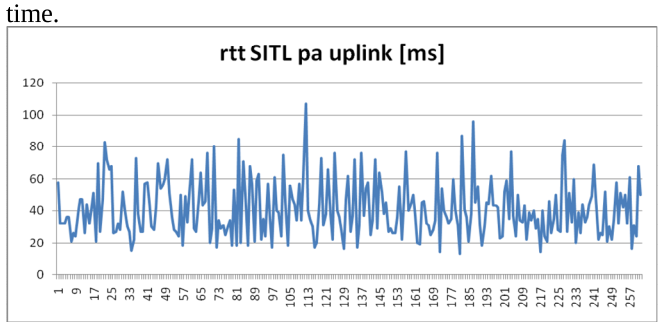

Figure 7. RTT delay for the simulated WiMAX link

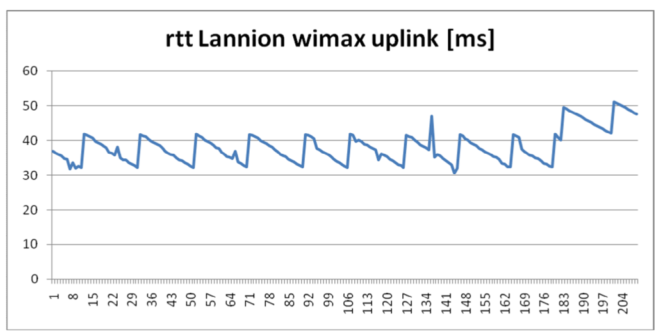

Figure 8. RTT delay for the real WiMAX link

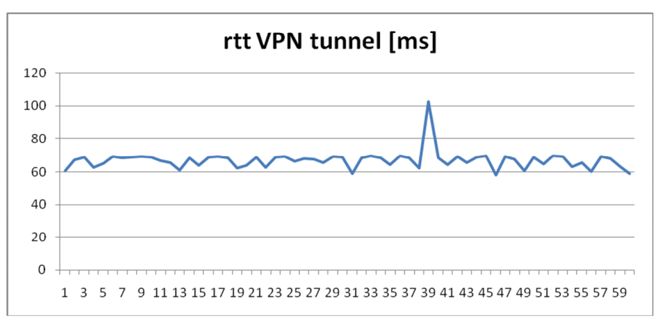

Figure 9. RTT delay for the VPN tunnel

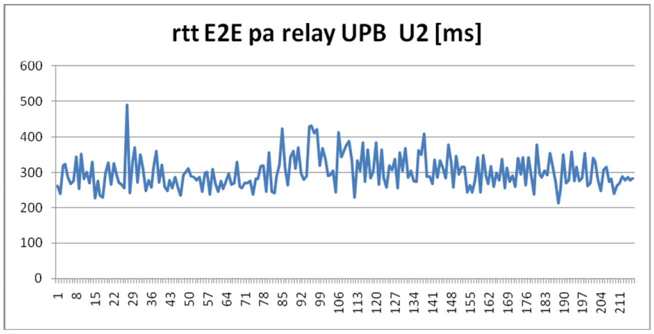

Figure 10. RTT delay for the second test suite

A second test suite was performed using the relay link in the real network and the simulated network. The traffic will travel end to end via two simulated WiMAX links, two real WiMAX links, and via the VPN GEANT tunnel. The RTT delay is shown in the Fig. 10. The mean end to end RTT delay is about 300 ms. This value is obtained by adding the delay introduced by the two additional WiMAX links and by the additional delay introduced by the hybrid simulated node and the relay node.

The jitter obtained in this second scenario is similar with the one obtained in the first scenario. This shows that the jitter introduced by the WIMAX equipments is small compared with the one introduced by the VPN tunnel. This is because the WiMAX link was used at a medium load, 5Mbps, which keeps the jitter at small values.

These measurements showed that the proposed WiMAX hybrid mesh nodes performs well in terms of delay and jitter introduced on the data streams. Such hybrid nodes having routing capabilities can be used to build backhaul infrastructure based on WiMAX technology.

B. *Smart antennas benefits evaluation*

Using the flexibility of the OPNET simulator, several test scenarios were developed in order to evaluate the gain added by the use of Smart Antennas in such a WiMAX backhaul network. The topology used for these experiments is presented in Fig. 11. The focus was on the simulated section of the network, the obtained results being gathered from the simulations outputs. The simulated part consists of a WiMAX network with one Base Station, BS1, connected to one of the SITL interfaces, one Subscriber Station, SS2, connected to the other SITL interface, and two WiMAX nodes, BS2 and SS1, connected together via Ethernet, which compose the hybrid mesh/relay node. The same WiMAX configuration parameters are used, as the ones in the scenarios presented in section A. The only change is that the same frequency band was used on all the simulated WiMAX nodes.

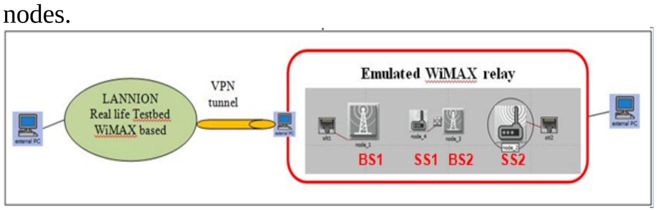

Figure 11. The topology used for smart antenna benefits evaluation

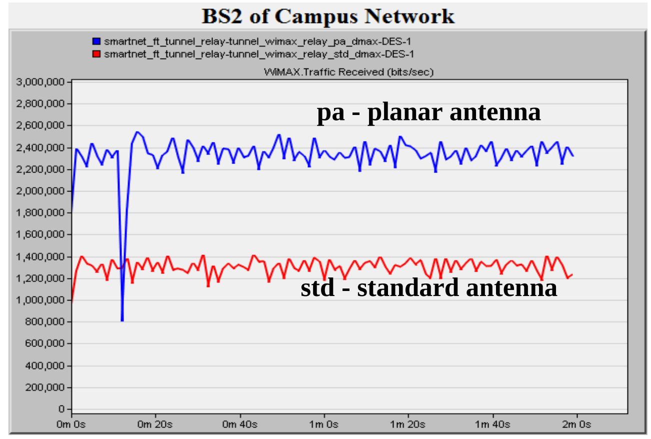

Figure 12. Traffic received by BS2: planar and standard antennas

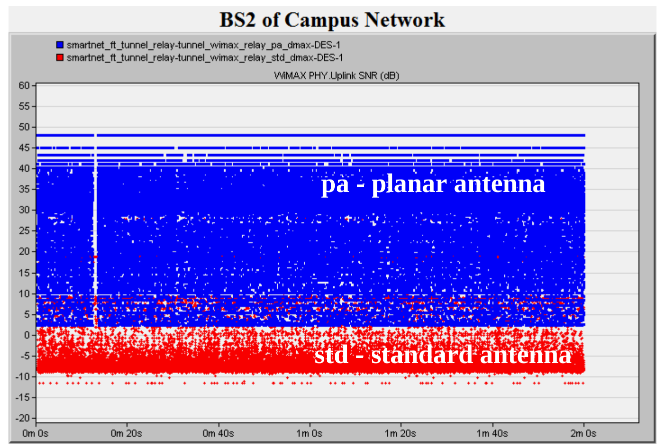

Figure 13. Uplink SINR at BS2: planar and standard antennas

This scenario will illustrate the spatial separation obtained using directional smart antennas. One stream of around 2.5Mbps was sent from the UPB laptop at the Lannion laptop. The traffic will flow through the path SS2-BS2-SS1-BS1 in the simulated network. The simulation was run twice: once with standard antennas on the WiMAX nodes, and once with the WiMAX nodes equipped with smart antennas.

The results are presented in Fig. 12 13 and 14. As it was expected, the results in the case when the directional smart antennas were used on the WiMAX nodes are much better than the ones obtained with standard omnidirectional antennas. This is mainly caused by the fact that the BS1 and SS2 are close to each other and they operate in the same frequency band. For the omnidirectional antennas, the interference level was significantly higher compared with the case when the beam switched smart antennas were used, because of the spatial separation between the BS1 and SS2 provided by the smart antennas. For the real hybrid relay station, due to its timing synchronization, this interference is avoided. The hybrid node used in the simulation, is based only on the spatial separation due to directional smart antennas and to the frequency separation.

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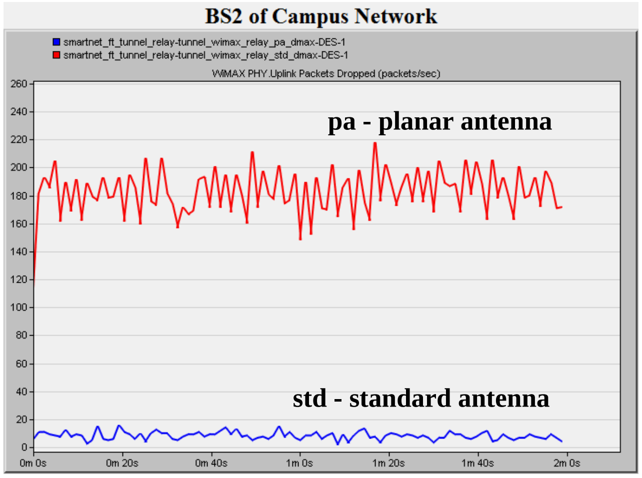

Figure 14. Packets dropped at BS2: planar and standard antennas

In figure 14, the packets dropped at BS2, for the cases when the simulated WiMAX nodes, are equipped omnidirectional standard antennas and directional smart antennas, are shown. The packets dropped by BS2, when omnidirectional antennas are used - red curve, are mainly the consequence of the interference between the nodes composing the hybrid node, BS1 and SS2. The packets dropped by BS2, in the directional smart antenna case- blue curve, are the consequence of the interference generated by the BS1 station and also by the interference generated from the secondary beams of the SS1 directional antennas.

Another advantage of using directional smart antennas is given by the higher gain on the beam direction compared with the equivalent omnidirectional antenna. Other simulation scenarios were used to illustrate this feature. The results showed higher throughput and bigger SINR obtained when the nodes were equipped with smart antennas [9].

V. Conclusion and Future Works

This paper presents an evaluation of a mesh network based on WiMAX, with nodes equipped with smart antennas. An experimental platform based on interconnection between an OPNET simulated WiMAX network and a real WiMAX network was built. A hybrid WiMAX mesh node, with routing capabilities, is proposed to be used for building a WiMAX network with mesh topology. An evaluation of the behavior of this hybrid node in a minimal mesh topology is performed. The simulations results presented in this paper illustrate that such an approach can be used for backhaul wireless networks. Also, by using smart antennas for fixed or nomadic WiMAX nodes, a significant performance gain, expressed in terms of capacity and coverage can be obtained for such networks. The proposed WiMAX mesh network with smart antennas is designed only for backhaul network. For mobile users access another radio should be used, or the Base Station should switch to omnidirectional mode to communicate with the mobile users. The smart antenna usage for mobile WiMAX nodes is still under 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.

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