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OPTIMISATION AND PERFORMANCE EVALUATION OF WiMAX MESH NETWORKS WITH IEEE 802.16J RELAYS

Mihai CONSTANTINESCU[1], Eugen BORCOCI[2], Victor CROITORU[3]

Releele non-transparente IEEE802.16j „multi-hop" constitue o soluție promițătoare pentru extinderea cu preț scăzut a acoperirii şi capacității rețelelor WiMAX. Apar însă anumite probleme, cum ar fi alegerea unei căi de la stația de bază prin releele disponibile, determinând în final o topologie tip arbore, sau alegerea unei căi cu interferență minimă. Aceasta lucrare urmăreşte evaluarea performanțelor unui astfel de algoritm de planificare şi rutare centralizată, ținând cont de efectele posibilelor interferențe generate de releele aflate în aceeaşi zonă de acoperire.

The non-transparent multi-hop relay based IEEE 802.16j networks type is a promising solution to extend at low cost the coverage and the capacity of the IEEE 802.16 networks. However, several issues occur, as the selection of a given path by the root BS among a possible mesh of relays to finally determine a tree topology or a path having the lowest interference. This work has as objective the performance evaluation of such a centralized routing and scheduling algorithm, while taking into account the effect of possible PHY interference of different relays placed in the same coverage area.

Keywords: smart antenna, interference-aware routing protocols, WiMAX mesh, non-transparent IEEE802.16j relays

1. Introduction

The IEEE 802.16j technology [1][2][3][4], and especially the transparent and non-transparent multi-hop relay based IEEE 802.16j networks type, is a promising solution to extend at low cost the coverage and the capacity of the IEEE 802.16 networks. The 802.16j relay solution is used to increase throughput or coverage in a WiMAX cell and is completely compliant with mobile IEEE 802.16e standards. The so-called "non-transparent" (NT) relays stations (RS) can be deployed in a multi-hop toplogy. The physical relay network is mesh-like, however the final logical relay topology is a tree-one. Therefore the

[1] PhD student, Faculty of Electronics,Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania
[2] Prof., Faculty of Electronics,Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania
[3] Prof., Faculty of Electronics,Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania

determination of this tree is necessary, being given an initial graph of the network. The tree can be computed by considering the “best” paths, where interference is lower. Also optimisation can be envisaged in scheduling, in order to exploit concurrent transmission opportunities to achieve higher spectral utilization..

This work has been partially conducted in the framework of an European research project SMART-Net (SMART-antenna multimode wireless mesh Network) having among its objectives studies and experimentations on hybrid mesh networks, including mobility issues. In SMART-Net Deliverables, D3.3a – "Preliminary description of cross layer optimization"[5], and D4.1 “Large Scale Simulation Testbed Specifications” [6], a solution and several centralized algorithms (extending an ideas presented in [7]) have been proposed as solutions for the joint routing and scheduling issues. The first issue is the selection of a given path by the root base station (BS) among a possible mesh of relays to finally determine a tree topology, by finding optimal paths having the lowest interference. An additional optimization consists in implementation of a scheduling mechanism that exploits concurrent transmission opportunities in order to achieve higher spectral utilization.

This work studies several scenarios having as objective the performance evaluation of a centralized routing and scheduling algorithm, while taking into account the effect of possible PHY interference of different relays placed in the coverage area of each other. Given the fact that the path selection is related to PHY interference information, this problem is both a routing problem and a cross-layer optimization one. Using directional antennas can improve the performance of the relay-based network in comparison with the traditional omnidirectional solution. Such cases will be considered in this study.

The structure of the paper is the following. Section 2 defines the network topology and the related considerations for the interference aware path selection algorithm. Section 3 presents the interference-aware scheduling algorithm. Section 4 is focused on analyzing the neighborhood interference effects. Section 5 describes simulations of several routing paths through an WIMAX mesh networks, IEEE802.16j NT-RS based, and analyzes if the minimum interference paths is enough relevant from the performance point of view. The same simulation scenarios are analyzed in Section 6, but considering smart/directional antennas for BSes and SSes. Conclusions and future work are presented in Section 7.

2. Interference aware path selection

The topology of BS and a set of NT 802.16j relays (NT-RS) coordinated by it is considered to be known. The signaling messages to support this determination are not in the scope of this paper. One has to determine the relay tree exposing minimum interference in case of omni-directional and then directional antenna use. The coverage areas and geographical placement of the nodes (BS, RSes) is known. The BS should determine a spanning tree logical structure covering all relays.

Several metrics can be defined:

1. Very simple additive interference metric i(k) - for a relay node k of a multi-hop route measures the number of nodes with which a node might interfere if they transmit simultaneously while using a single frequency resource. The metric has a low granularity because it does consider neither geographic distance not transmission power of the two interfering stations;
2. A more elaborated metric is based on measuring the degree of interference seen by an NT-RS from each interfering station and cumulates these figures in a parameter expressing the total degree of interference seen by an NT-RS.

The first primary valid assumptions set have been: the configuration is fixed (or nomadic); the configuration is not yet fully optimized in terms of the geographical placement of the relays; the coverage areas of the relays are partially overlapping (to create the multi-hop topology and to accommodate MS mobility) and so interference could result; omni-directional antennas and a single frequency resource are supposed to be used;

In terms of acquisition of the topology and metric information by the root BS, two solutions are envisaged:

- Static: BS knows the topology, the distances (therefore the placement of the relays) and the coverage areas; BS can determines all pair of nodes being in a mutual interference relationship and construct the interference graph;
- Dynamic: BS has only partial knowledge of the interference graph, but a signaling between NT-RS on some management channels is possible (low speed is used, for robustness) over the non-optimized topology; so BS can obtain desired information about degree of interference from the each NT-RS relay itself. This solution is more powerful given that it can adapt to the changing conditions of the real network. On the other side, continuous monitoring of the interference degree is necessary at each NT-RS, plus the collection of such information by the root BS.

Fig. 1 shows an example of a BS and a set of NT-RSs representing the interference graph (for details see [8] [9]).

The simple interference metric i(k) value is written close to each node. One can see that for a target NT-RS as RS11 the Path1 is better than Path2 (cost 13 versus 17). For a given graph, a modified Shortest Path First (SPF) algorithm can be applied to the graph, to compute (at the BS) the spanning tree for such a topology by using the simple metric defined above. Variants of the algorithm could be an adapted version of the original algorithm proposed in [7] and the Dijkstra Algorithm for additive metric defined above.

Note that this procedure does not eliminate the interference, but only minimizes it. The scheduling has the task to eliminate the interference.

The usage of directional antennas modifies the interference graph reducing the interference by cutting some edges. Consequently the ST tree computed by the algorithm will be modified. The algorithm for path selection is presented in [8] [9].

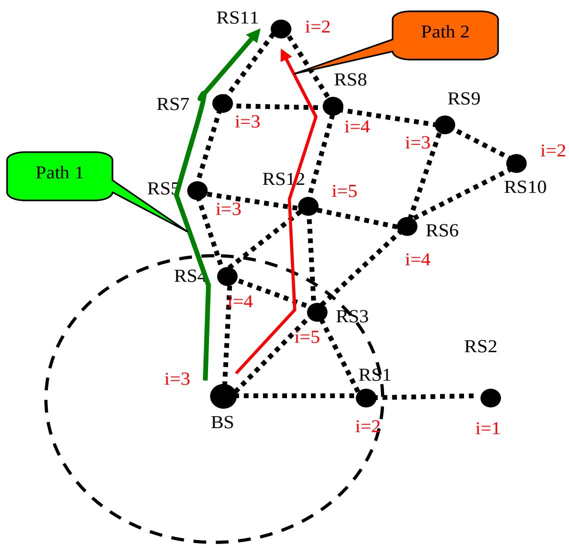

Fig. 1. Example of the interference graph for an NT-RS network configuration

3. Interference-aware scheduling with spatial reuse

The interference-aware scheduling algorithm [8] [9], exploits concurrent transmission opportunity in different regions of the ST tree, in order to increase the spectral utilization (by frequency reuses), and finally get a higher system throughput. It maximizes the number of concurrent transmissions, without creating exceeding interference for other simultaneous transmissions.

The scheduling process takes also into account the traffic capacity request Req(k) of an RS node k from the Mesh BS. The BS grants radio resources according to the capacity requests of all RS nodes and the path information provided by the ST. Having the route information from network entry and the initialization process, the node capacity request Req(k) can also be equivalently represented in terms of link demands ReqL(j) for every link j. The scheduling algorithm iteratively determines ActiveLink(t), which is the set of active links at the time t. In each allocation iteration t, a link with the highest unallocated traffic demand is selected for next allocation of unit traffic.

To satisfy the Signal-to-Interference Noise Ratio (SINR) constraints of concurrent transmissions, a Blocked_Neighbor(k) function is used to exclude interfering links that are located in the neighborhood of k. The iterative allocation continues until there is no unallocated capacity request. Fig. 2 shows the nodes allowed to transmit concurrently, thus obtaining a higher throughput.

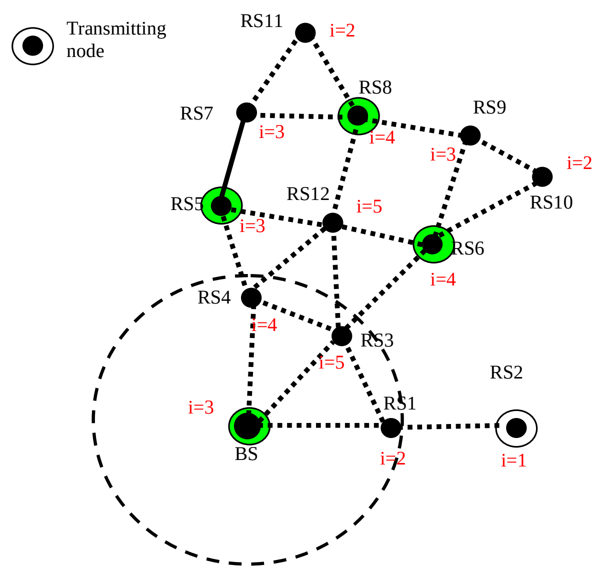

Fig. 2. Transmission mode with spatial reuse of frequency

4. Neighborhood interference effects

The above algorithms are of real usage in an interfering environment. Their impact on the increasing the overall network capacity is greater if the degree of interference is greater, provided that some less interfering paths still exist. Therefore simulation studies have been performed, in order to evaluate quantitatively the effect of interference in different context. A detailed presentation of methods and simulations results are performed in [8] and [9].

The objective of this section is to analyze if the effort to find minimum interference paths is enough relevant from the performance point of view. Fig. 3 presents a network IEEE 802.16 simulation model, implemented in OPNET v.16 [10], used to analyze the importance of interference among other conditions of WiMAX environments and to quantify the interference effect on application throughput. This is a proof that less interference finding path previous algorithms are valuable for performance increasing.

The model consider six BSes 802.16, denoted by BS_0, ..., BS_5, using the same frequency resources and a subscriber station MS which is fixed between the BSes.

The MS antenna gain (omni-directional) is 10 dBi and transmitting power is maximum 0.25W. All BSes transmit using the same power (0.5W) and have antenna gain of 15 dBi. Therefore interference is produced. A flow between MS and external server is established (CBR, 64kbps). The MS is physically and logically connected to BS_0 which is the closest. The parameters for BSes and MS are given in Fig. 4.

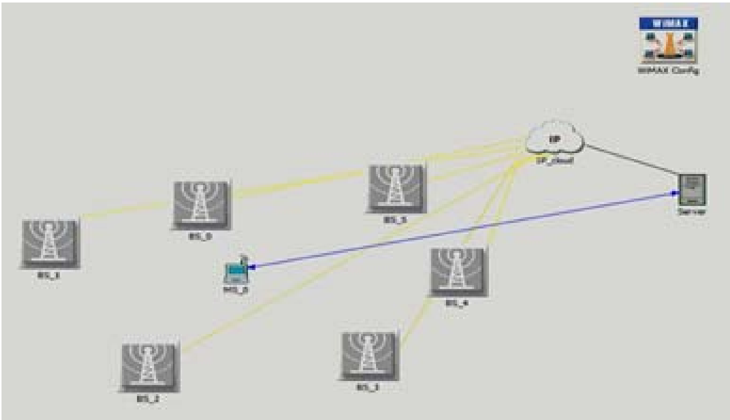

Fig. 3. Network topology for evaluating the interference effect

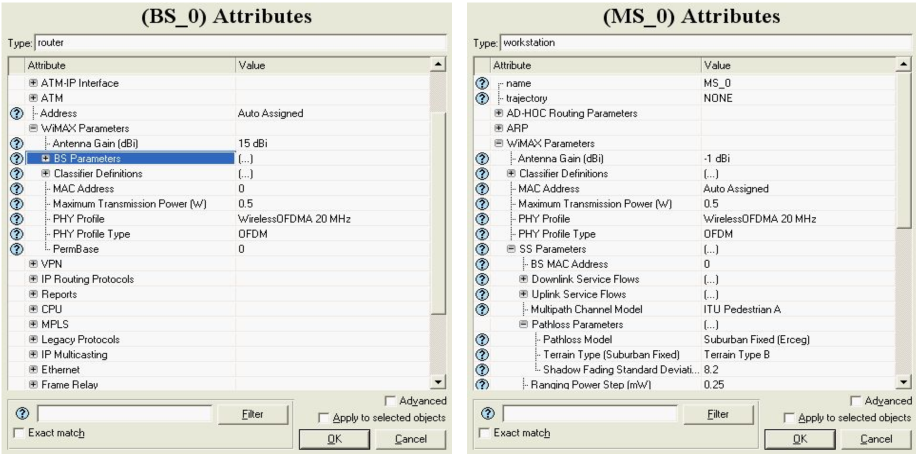

Fig. 4. BS and MS parameters for related mesh topology

The radio propagation channel model considered in simulations is the Suburban Fixed (Erceg) pathloss one, simulating one of the following terrain types: hilly terrain with moderate-to-heavy tree densities (type A); mostly flat terrain with light tree densities (type C); a compromise between type A and C.

To evaluate the effect of interference upon MS throughput several experiments have been conducted in which:

- BS_0 only is active,
- BS_0, BS_1 only, are active,
- ….
- BS_0, ..., BS_5 are all active.

Note that only BS_0 carries real traffic. Therefore BS_1, ..., BS_5 produce only control traffic on Downlink. However, the MS throughput decreases as long as several interferers are active around it (Fig. 5). The cumulative throughput diagrams show that, when BS_1, ..., BS_5 are active, a decrease of approximately 20% is produced. It is expected that, if active users traffic are manipulated by the BS_0.. BS_5, the effect on MS is higher and can be 30-40%. Therefore, selecting a less interfered path is supposed to bring a gain of 20-40% in the throughput.

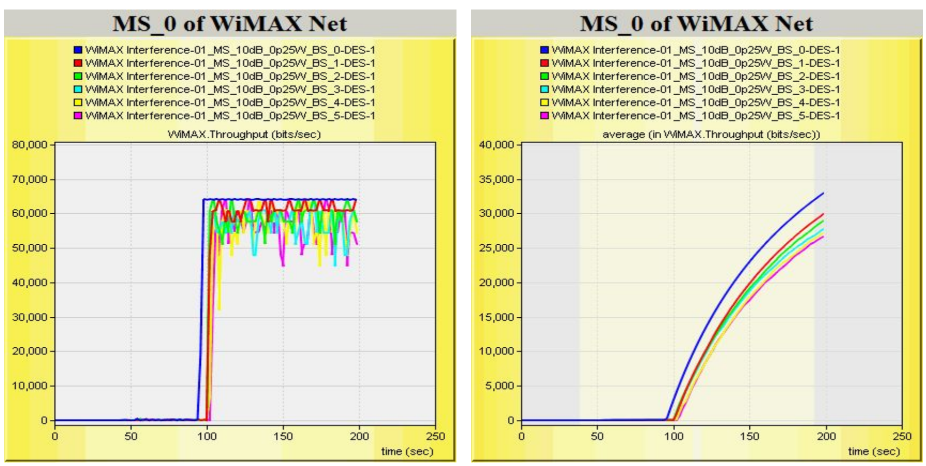

Fig. 5. Throughput at MS for various degree of interference

5. Mesh network with interference

The objective of this section is to simulate several routing paths through an WIMAX mesh networks, IEEE802.16j NT-RS based, and to analyze if the minimum interference paths is enough relevant from the performance point of view. Given the fact that NT-RS are not supported by the current versions of OPNET releases, an emulation of a mesh topology containing relays has been defined. In this configuration each “relay” is composed by two elements: an SS which receives the flow from the previous BS and a retransmitting BS, linked by wired I/F with the SS. While quantitatively the behavior of the pair SS-BS is not similar at MAC level to that of an NT-RS, for the interference-related purposes of this study, the model is enough relevant.

Fig. 6 presents the considered mesh network topology. The traffic flow is flowing from an external IP server to BS station and then on one of several paths towards S8.

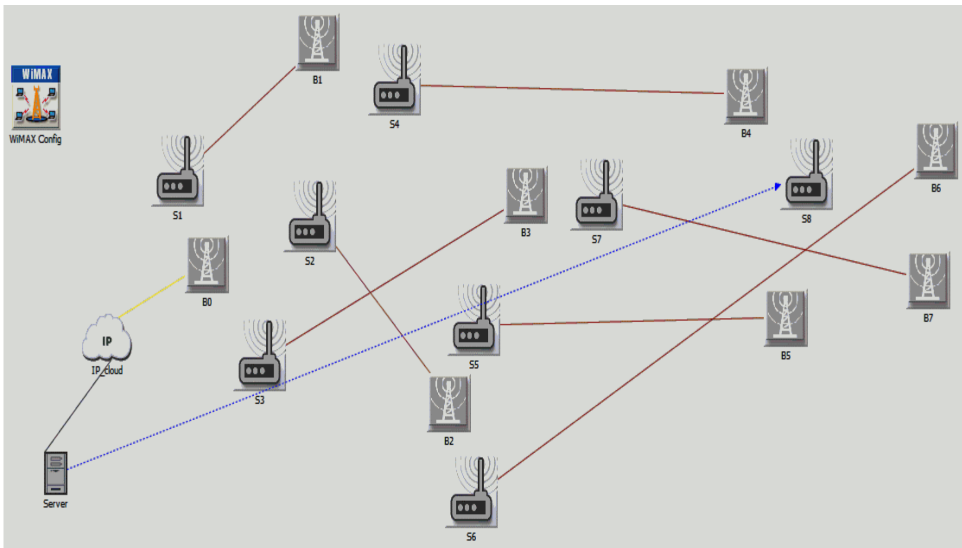

Fig. 6. Mesh network model for evaluation of interference effects on paths

Several variants of paths from B0 to S8 will be considered in this model:

- B0 - S1/B1 – S4/B4 – S8 – path denoted shortly: 1-4-8
- B0 – S2/B2 – S5/B5 – S8 – path denoted shortly: 2-5-8
- B0 – S2/B2 – S6/B6 – S8 – path denoted shortly: 2-6-8
- B0 – S3/B3 – S7/B7 – S8 – path denoted shortly: 3-7-8

On this topology the effect of interference has been studied on different paths. First, the decrease of throughput (mean value) along the 1-4-8 path due to interference is observed in Fig. 7 left. Each intermediate relay introduce a throughput loss, generating a succesive decrease of application throughput. The same effect is seen also on other paths as presented in Fig. 7 right for the path 2-5-8. Hence, each path is affected by interference. However, the application throughput obtained on path 1-4-8 is greater than one on path 2-5-8, due to the fact that the interference is lower on the first path than on the second one.

Fig.8 presents in details (temporal diagram) the decrease of throughput on path 1-4-8, and the downlink (DL) signal-to-noise ratio (SNR) observed on S1 on that path.

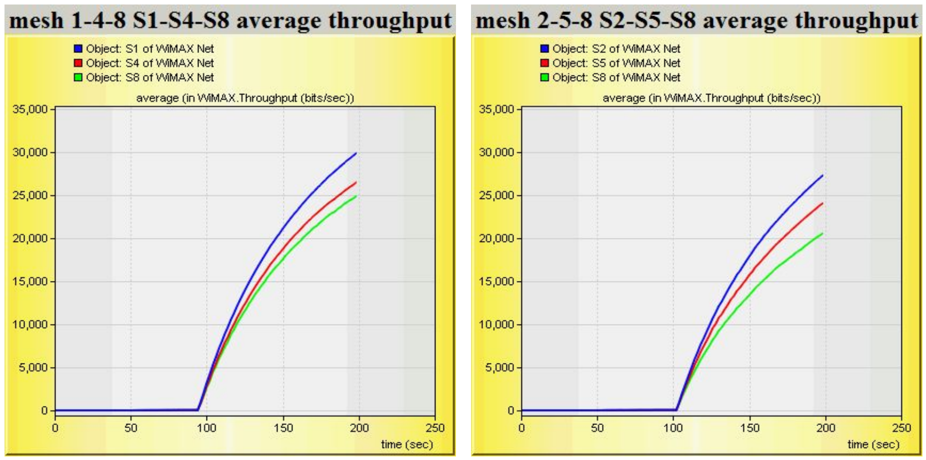

Fig. 7. Decrease of throughput on 1-4-8 path due to interference, and on 2-5-8 path respectively

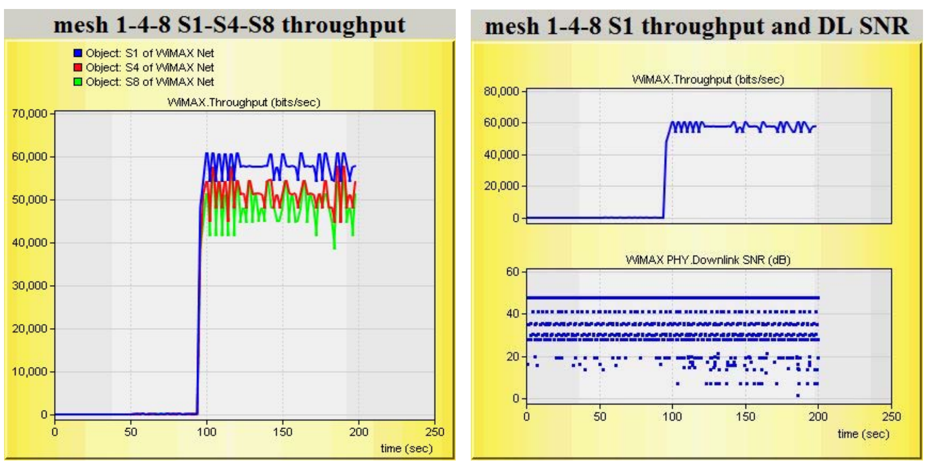

Fig. 8. Decrease of throughput on 1-4-8 path due to interference (temporal diagram)-left and DL SNR observed at S1-right

The diagrams of the interference produced by several interferers to a given station are presented in Fig. 9. As a measure of the interference, it was taken the SNR seen from other BSes than the current serving one. For instance at S1, on the path 1-4-8 we see that decreasing DL MAP SNR at -7dB, -13dB, -14dB, etc. are observed from respective: B1, B2, B3, ….while the SNR observed from the serving BS0 is 4dB. These values can be summed in a metric to characterize the degree of interference observed at S1. Similar set of values are observed at S4, S8. Considering another paths we may obtain also similar results but different only quantitatively, as in Fig. 10.

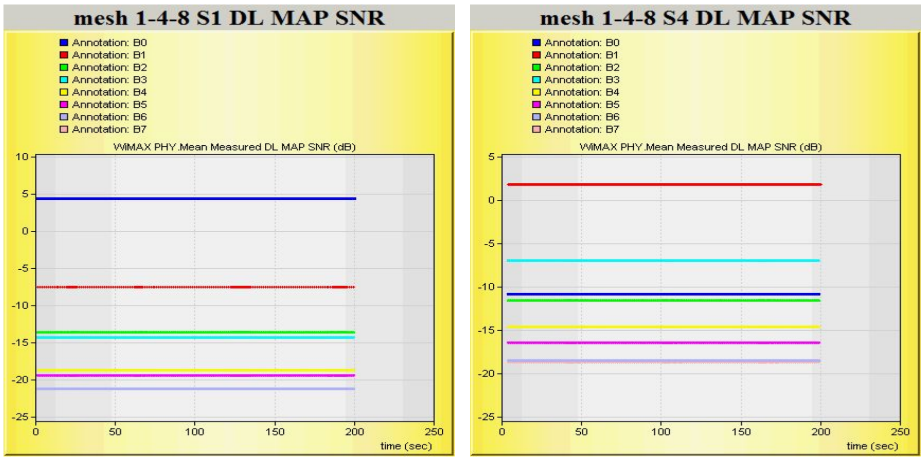

Fig. 9. Downlink SNR observed by S1, respectively by S4, from B0 and other different BSes generating interference

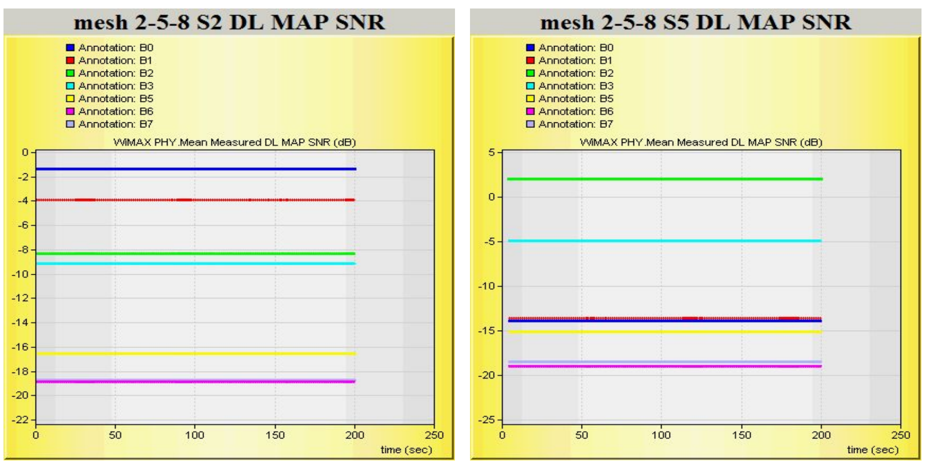

Fig. 10. Downlink SNR observed by S2, and respectively by S5, from B0 and other different BSes generating interference

6. Smart antenna use in WiMAX mesh network emulating the non-transparent IEEE802.16j relays

In order to evaluate the smart antenna role within the interference-aware routing protocols, the same NT-RS relay mesh network from Fig. 6 is considered, but with BSes and SSes using omni-directional and/or directional antennas (Fig. 11**Error! Reference source not found.**). A data traffic from server to S8 is configured, and several BSes, acting as sources of interference, are deployed near S4.

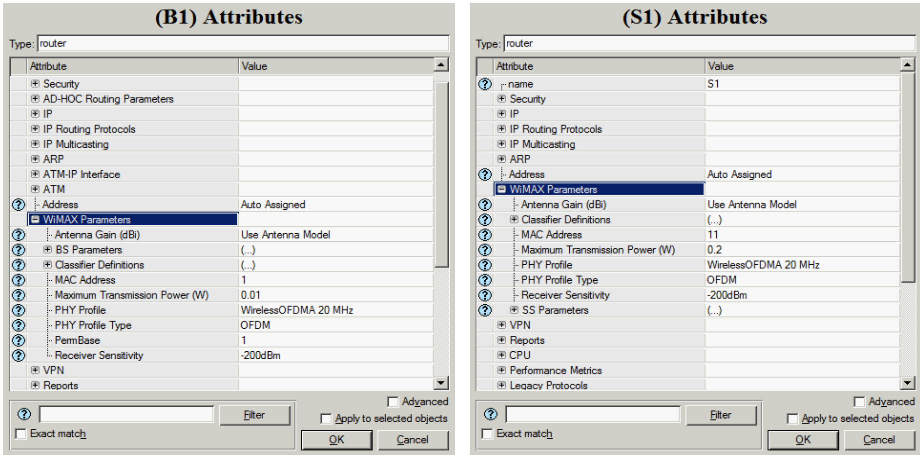

Fig. 11. BS and SS configurations

BSes have omni directional antennas, 14 dBi gain (Fig. 12 a)

SSes have omni directional antennas, 14 dBi gain, or directional, multi beam antennas, **Error! Reference source not found.** (Fig. 12 b).

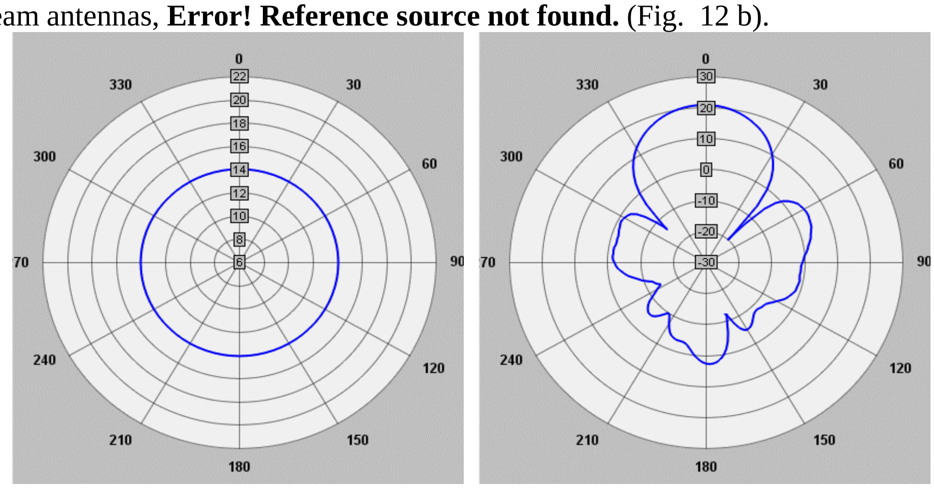

Fig. 12. Omni directional 14dBi (a) and directional, multi beam antenna patterns (b)

First set of scenarios is related to SS using omni directional antennas, 14 dBi gain. The effect of an interference source on application throughput measured on S8 is analyzed. The interference could be absent, low or high, depending on the power level chosen for the 4 BSes named perturbation1 to 4. The increase of interference determines a decrease of applications throughput (Fig. 13). When no perturbation sources are activated, the application throughput measured on S8 is around 100,000 bps (blue). When perturbation source are activated, but with low power, the application throughput measured on S8 is less than 70,000 bps (red).

Increasing the power of perturbation sources, the application throughput measured on S8 decrease to less than 40,000 bps (green).

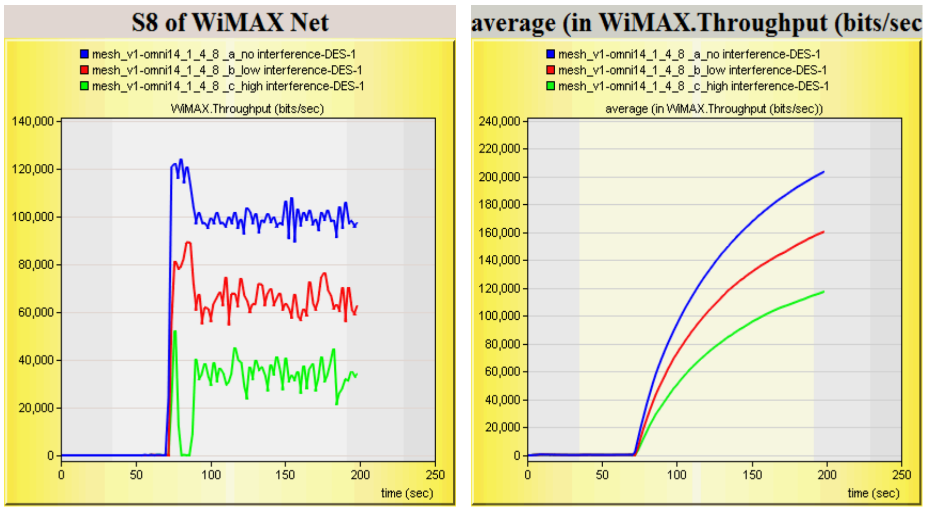

Fig. 13. Effects of interference on application throughput measured on S8. Comparative graphs, omni directional antennas, 14dBi

The second set of scenarios is related to SS using directional, multi beam antennas. The BSes have omni directional antennas, except the last scenario, named “mbeam_1_4_8 c_high interference_ mbeam”, in which the perturbation sources are using multi beam antenna, instead of omni directional ones, as in the rest of scenarios.

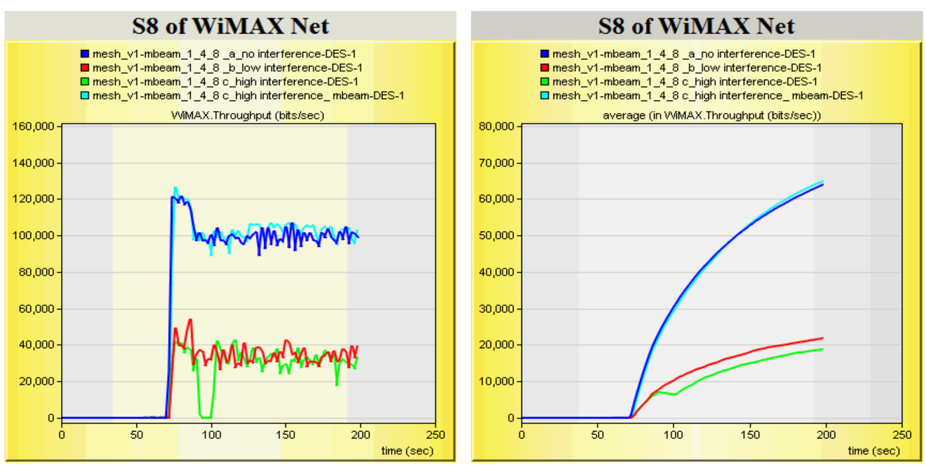

Fig. 14. Effects of interference on application throughput measured on S8. Comparative graphs, directional, multi beam antennas

The effect of an interference source on application throughput measured on S8 is analyzed. The interference could be absent, low or high, depending on the power level chosen for the 4 BSes named perturbation1 to 4.

The increase of interference determines a decrease of applications throughput (Fig.14). When no perturbation sources activated, the application throughput measured on S8 is around 100,000 bps (blue). When perturbation source are activated, but with low power, the application throughput measured on S8 is less than 40,000 bps (red). Increasing the power of perturbation sources, the application throughput measured on S8 is decreasing again (green).

Using directional, multi beam antennas on perturbation sources, the effect of interference due to the perturbations are almost none (light blue), even the perturbation sorces are activated with the some power level coresponding to high interference on the previous cases.

When no perturbation sources are activated, the application throughput measured on S8 is almost the same, 100,000 bps, for both omni directional antenna use (red) and directional, multi beam antenna (blue) (Fig. 15**Error! Reference source not found.**).

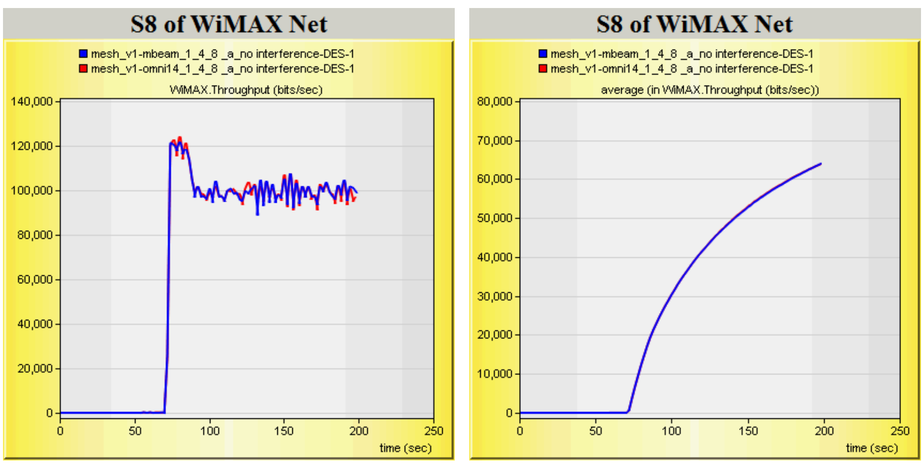

Fig. 15. Application throughput measured on S8. No perturbation sources activated. Omni directional (red) and multi beam antennas (blue) on SSes.

When perturbation source are activated, but with low power, the interference effects on application throughput measured on S8 are lower (higher application throughput – red) for omni directional antennas use compared with the smart antennas one (blue) (Fig. 16). These results are explained by the fact that smart antennas are more sensitive to interference on the directional beam than omni directional antennas.

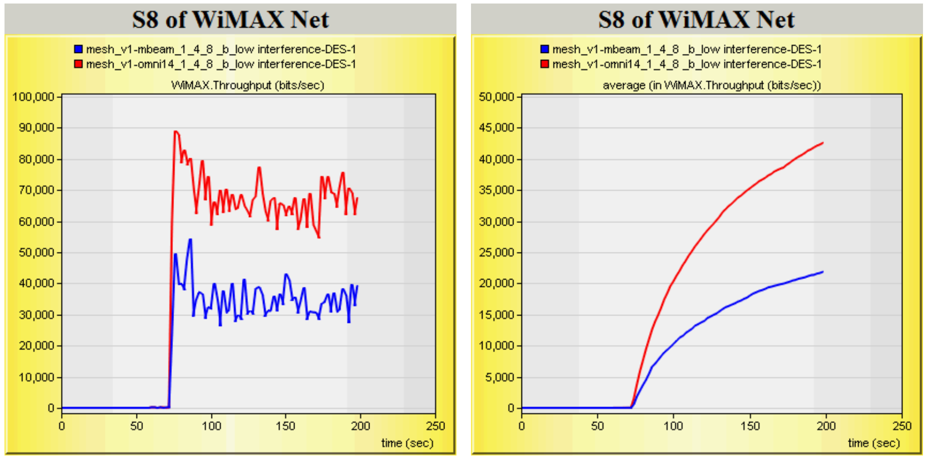

Fig. 16. Application throughput measured on S8. Perturbation sources have omni directional antennas and are activated with low power. Omni directional and multi beam antennas on SSes

When the power of perturbation sources is increased, the application throughput measured on S8 is decreasing again for both omni directional (green) and multi beam antennas (blue) (Fig. 17), but the high interference effects are almost the same for both omni directional and smart antenna use. Application throughput for perturbation source with omni directional antennas and low power is used for reference (red). Note that till now all BSes have used omni directional antennas only.

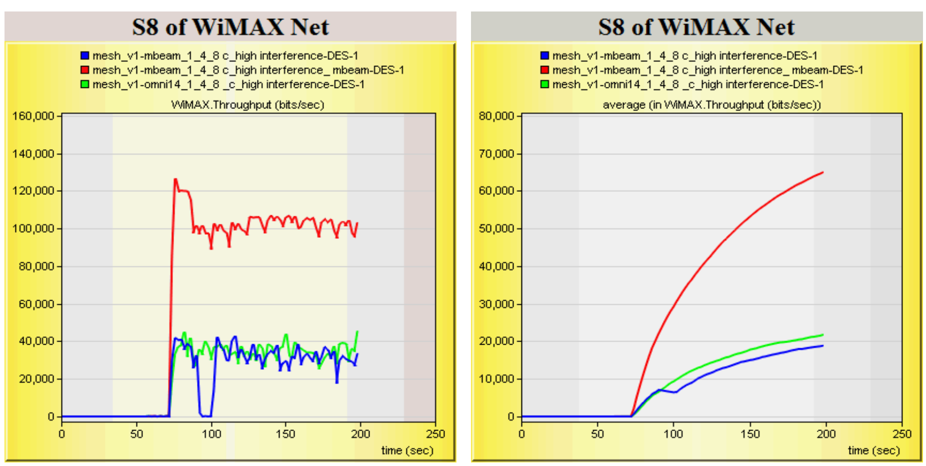

Fig. 17. Application throughput measured on S8. Perturbation sources are activated with more power than on low interference scenario. Omni directional and multi beam antennas on SSes

A better comparison between omni directional and multi beam antenna use is shown in Fig.18**Error! Reference source not found.**, considering both omni directional and smart antennas for BSes.

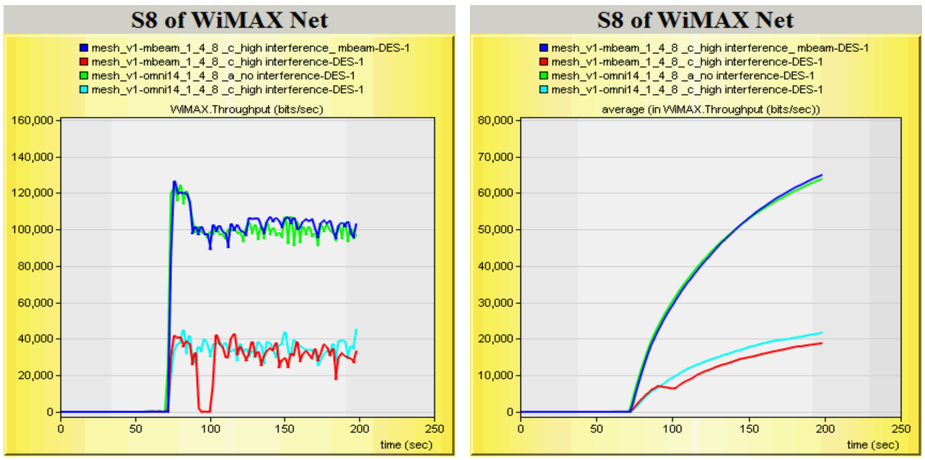

Fig. 18. The benefits of directional, multi beam antennas use

On high perturbations, the omni directional antenna for both BSes and Sses (light blue) has some better results than multi beam antenna for Sses only (red), but the throughput is registering a big decrease for both cases. The perturbation sources BSes are simulating the effects of interference due the rest of BSes and SSes on a specific station (S4 in these scenarios) on a more complex mesh network topology. However, using directional, multi beam antennas on all stations (blue), not only on SSes, the throughput is the same as for no perturbation case (green), so the full use of smart antenna could avoid almost totally the interference effects, and especially the high level one.

7. Conclusions

This paper has evaluated the performance of the non-transparent relay solution to assess throughput increase while applying the routing and scheduling algorithms in interference aware mode. Simulation models have been proposed and a large number of simulations have been performed, considering both omni directional and directional (beam forming) smart antennas. The NT IEEE802.16j relays behaviour are emulated by BS-SS pairs (from point of view – interference study). The tree of relay (routing) is computed, based on an interference aware additive metric and algorithm. The simulation studies have shown that the effect of interference on a multi-hop topology can decrease seriously the throughput on a path. These results provide the reasoning to argue that algorithms based on less-interference path selection can improve the overall performance of a multi-hop relay network.

Further simulations should combine the interference-aware algorithms with centralized QoS mechanisms within the WiMAX networks, to evaluate the overall performance. A full IEEE802.16j non-transparent relay OPNET model should be developed and used in such simulations.

Aknowledgement

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