Introducing and Evaluating a Relaying Concept for the IEEE 802.16 Wireless Metropolitan Networks

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Abstract

Wireless metropolitan area networks constitute one of the most rapidly evolving research areas. Indicative of the interest this area presents is the newly standardized IEEE 802.16. One of the most interesting, as well as, challenging extensions is to provide relaying capabilities to such networks. In this paper we present such a relaying concept which we believe combines simplicity and efficiency. This model is developed on top of the WiMAX model provided for the NS2 network simulator. Through numerous simulations an evaluation of the NS2 WiMAX model, as well as, the proposed relaying concept is presented considering two different simulation scenarios.

1. Introduction

Developing wireless network that are capable to provide broadband access to large metropolitan areas is of great interest since it is an area that concerns both research and industry domains. A major representative of these efforts is the IEEE 802.16 standard “Air Interface for Fixed Broad Wireless Access System” [1]. The main target of this protocol is to provide performance comparable to traditional wired network like T1 and DSL networks, to last-mile wireless metropolitan networks. According to the standard the physical layer supports OFDM (orthogonal frequency division multiplexing) and SC (single carrier) transmission technique and theoretically it supports data rates higher than 120 Mbps in 28MHz channels.

Numerous applications can benefit from the flexibility and efficiency that a wireless metropolitan network can provide. Development of traditional wired infrastructures can be very difficult, not feasible or not efficient in many cases such as when other wired infrastructures don’t preexist, topological conditions are harsh or vast areas must be covered efficiently as well as rapidly.

Being a newly developed and standardized technology a lot of effort is devoted in extending its specifications towards several directions. The first such effort was standardized in 2005 as the “e” version of the IEEE 802.16 standard that provisioned mobility support. This area concentrates many high quality research works [2]-[5].

A second extension which attracts great deal of interest and actually is the focus of this paper is provisioning for relaying functionalities and specification of respective amendments to the standard. Indicative of the importance of this extension is the fact that a specific IEEE Task Group (TGj) is formed to support this effort. Also considerable research contributions are made to this domain such as [6]-[9],[11] which focus mainly on in-band approaches and the mesh mode of IEEE 802.16 standard.

However, since this technology is product oriented by nature this paper focuses on other criteria that should also be considered when trying to design a relaying concept such as implementation simplicity and efficiency. Additionally this work considers connection oriented communication which provides higher service quality compared to mesh mode. Finally [15] presents a relative research work utilizing advanced antenna techniques on BSs. This work aims to extend this approach considering the use of such techniques on RS stations and evaluating potential performance benefits.

The rest of the paper is structured as follows: in section 2 necessary background information is given. Moving on to section 3 the proposed relaying concept is presented. The simulation environment, as well as, the appropriate model is described in the 4th section while in the 5th indicative evaluation results are given. Finally we present the main conclusions, as well as, some future directions.

2. Background on the IEEE 802.16 standard

The main part of the IEEE 802.16 standard deals with physical and medium access control layer and the respective service access point as (figure 1). As usual, there is a vertical layer concerning management affecting
each sub-layer which, however, it’s not of main interest in this paper and therefore omitted.

The convergence sub-layer (CS) provides the necessary functionality for transforming and mapping of external network data in order to support a variety of different higher applications and transferring modes. On the lower end the security sub-layer provides adequate functionality for authentication, secure key exchange and encryption.

In the middle the core MAC functionality is provided by the “Common Part Sublayer” which includes system access control, bandwidth allocation, connection establishment, and connection maintenance.

The IEEE 802.16 supports two functional modes: the point-to-multipoint (PMP) and the mesh mode. The PMP follows a more fixed infrastructure concept where a specific area is covered by a base station (BS) and several clients SSs are specifically associated to it.

On the other hand following the mesh mode the network is organized in a much more ad-hoc manner. In this way each station can also act as forwarder in order to relay a packet when direct communication is not possible or when relaying is more efficient. However it must be noted that in practical scenarios the need for BS will still exist especially for connection to a backhaul network [10].

Finally, in order to have a clear view of the PMP mode, the frame structure in TDD mode is depicted in figure 2 as extracted by [12].

3. Proposed Relaying Concept

The main idea is to come up with a design of a node that can efficiently provide forwarding to data operating in the PMP mode.

Key feature of such a design (also in the context of TGj) is to guarantee maximum degree of backward compatibility. The WiMAX technology is already active and many products exist on the market. Being compatible with these products is an important added value for any design.

Basic assumption in our design is the RS support of “true sectoring”. According to this technique the RS station controls multiple directional antennas. Consequently, each sector is controlled by a dedicated PHY processor. From the MAC point of view there is a single MAC processor capable to provide multiple instances. So each PHY processor – MAC instance comprise an independent system not interfering with any other in the same station. Figure 3 shows the conceptual composition of a three sector station.

Utilizing this assumption the RS incorporates the functionalities of both a standard compliant BS and a standard compliant SS. It is important to point out that following this design no modifications are needed to the standard 802.16e. Figure 4 shows a minimal setup where the RS supports two independent sectors. Sector 1 behaves like a standard SS and it is associated to the BS following the typical procedures. On the other hand sector 2 behaves like a BS towards the associated SSs (SS1-SS3). Thus, it is the responsibility of the MAC processor to correctly transfer data from one instance towards one where the final SS destination is associated.

Having in mind this basic setup in figure 4 and considering a downlink transfer, sector 1 MAC instance receives the data, and passes on the data to the 2nd sector MAC instance (in multiple sector an additional task would be to determine the correct sector). In second phase data are rescheduled and transmitted to the final SS destination.

Summarizing we propose an RS design concept offering appealing features and performance enhancement. It provides maximum degree of backwards compatibility since no modifications will be needed. It’s very flexible and utilizes already existing and tested functional principles, such as true sectoring. Furthermore it provides an efficient way to exploit spatial reuse. This is a key advantage since SDMA techniques are very promising and it is proven that omnidirectional
transmission and MAC protocols operating under this assumption lead to considerable waste of both bandwidth utilization and power consumption.

**Figure 3. True Sectoring Support**

MAC PROCESSOR 1

Sector 1

MAC INSTANCE 1

Figure 4. Minimum setup for the proposed RS concept

In addition, designing scheduling algorithms can be proven much more efficient and handover procedures are more straightforward and faster to complete when a SS moves from one sector to another.

**4. Simulation Model**

In order to evaluate this concept the well-known and widely utilized network simulator NS2 is used and in particular its 2.29 version [14]. The implementation is made on top of the WiMAX model developed by the NIST [13]. This model concentrates many appealing characteristics either available at present state or scheduled for future versions. In order to evaluate the proposed architecture all necessary characteristics are available. Additionally, many important features are scheduled for future versions. Thus extending this model we implemented the minimum setup of our RS concept as shown in figure 4.

**5. Evaluation on the RS model**

**5.1 Simulation Setup**

The main goal of the simulations conducted is twofold. On one hand the functionality of the NIST WiMAX is studied. On the other hand an evaluation of the proposed RS concept is attempted in two different simulation scenarios.

In the context of these scenarios some common parameters are defined as follows. In all cases data packets of 1500 bytes are considered. Simulation duration of 250 sec is selected. This duration is sufficient so as to have an accurate evaluation of the network behavior. However traffic is inserted in the network for 200 sec. The difference in the time duration aim in providing eventually adequate time for packets created near the 200 sec moment to reach their destination. Additionally traffic sources have different starting points. The traffic generators defined are creating packets following a constant bit rate so that the workload would be inserted in the network in a uniform way. In this way conclusions concerning the way the network handles the workload are more objective and don’t get influenced by other factors like the workload distribution. Another layer decisively influencing network performance is the network layer. Again aiming in isolating the MAC performance UDP is utilized which imposes the minimum control effect in data transferring contrary to the TCP protocol family. Finally the transmission range for all stations is 500 meters.

**5.2 The Effect of Varying Modulation Schemes and Transmission Rates**

As mentioned before two simulation scenarios are considered. The first one is depicted in figure 5. According to this scenario four SS are considered. Using the NIST model (default from now on), shown by the blue arcs, all four stations are inside the transmission range of the BS and approximately 400 meters from the BS. Contrary when the proposed model is evaluated (B2BRS from now on), shown by the red arcs, the four SSs are 800 meters from the BS. An RS is deployed, located at 400 meters forwarding data to the final destination. The main parameters in this case are the modulation scheme and transmission rate. Moving from the most robust modulation scheme to the one providing the higher capacity the following schemes are utilized:
BPSK(1/2), QPSK(1/2), QPSK(3/4), 16QAM(1/2), 16QAM(3/4), 64QAM(1/2), 64QAM(3/4). On the other hand the per data flow transmission rate varied taking the following values: 200, 400, 600, 800 reaching 1000Kbps. So overall the workload imposed on the network varied from 800 to 4000 Kbps providing adequate range to evaluate the functionality of the B2BRS.

In figure 6 the mean packet delay measurements are depicted considering the default model. The first observation is that BPSK and QPSK(1/2) clearly provide the worst performances. The channel capacity under BPSK is very low, leading to a very high increase rate for workload higher than 0.2Mbps/flow which makes it inadequate for most applications the 802.16 aims at. Considering QPSK(1/2) although the performance is much better compared to BPSK still saturation is evident after 0.8Mbps/flow shown by the abrupt increase of the mean delay measurement. However all the rest of the supported modulation schemes do provide adequate channel capacity to handle the imposed workload.

A troubling observation that needs elaboration is the edge forming at about 0.6Mbps. In order to explain it, it must be pointed out that these measurements are end-to-end, that is, from the moment a packet is created at application layer by the CBR generator till the moment it is successfully accepted by the destination application layer. So after some careful examination of the functioning the model and some extra simulations we concluded that it has to do with the synchronization between the CBR traffic and the frame rate. Thus it is possible for a specific data rate, the CBR packet arrive just after the uplink transfer between the connection queue and the transmit buffer. Therefore it needs to wait for the next frame thus adding delays.

Moving on to the B2BRS the mean delay measurements are depicted in figure 7 and, in order to study the increment of delay in figure 8 the delay difference is shown.

Comparing the figures 7 and 8 the main observation is that although there is a clear delay increase, the network presents an overall similar behavior pattern. This is a very positive feature that enhances the stability of the system being aware that the network behavior remains almost unaffected, even with some delay penalty.

In order to better evaluate the delay penalty in figure 8, the delay increment due to the RS deployment is shown not considering BPSK modulation which in both cases performs quite poorly.
As depicted the highest delay is observed for the QPSK(1/2) but since this modulation produces not efficient performance (saturation after 0.8Mbps/flow), no further analyzes will be made.

An important characteristic is that measurements for all other modulation schemes lay very close. However there is clear tendency towards lower delay increase as we move from lower to higher capacity scheme. For example considering the three higher capacity modulation schemes (64QAM ¾, 64QAM 2/3, 16QAM ¾) the delay increase is independent of the transmission rate, except form the 0.6Mbps area where the increase is observed for reasons explain before.

In the following two figures, measurements concerning the successfully transmitted packets are presented and comparison between the default and the B2BRS models can be made.

Figure 9 clearly depicts the capacity capabilities of each modulation scheme. As expected, BPSK performs very poorly followed by QPSK1/2. The continuously linear increase of the successfully transmitted packets for all the rest of the modulation schemes reviles a capacity adequate for the workloads imposed. However, the most important observation comes from comparing figure 9 with figure 10.

As it is shown, measurements are almost identical, meaning that the capacity of the network is not influenced by the RS node. We should mention that these measurements assume same modulation scheme for both links when RS is enabled as well as for the direct link to which they are compared to. Overall it is shown that even with some small delay penalty the capacity capabilities remain the same with and without the RS node which is very positive.

5.3 The effect of varying data flows

The main parameter of the second scenario is the varying number of concurrent data flows. Altering the number of the data streams that the 802.16 scheduler must service stress the system in two ways. Firstly the workload increase which is also the case in the 1st scenario. Secondly servicing concurrent requests stresses the system in an additional way. Consequently, evaluating the effect of considering an RS node under these network conditions is very important. Figure 11 shows the deployment of stations.

As shown in figure 11 the concurrent data flows vary from 4 to 10 either considering RS or not. Taking into account that the per flow data rate cases include 0.6Mbps and 1Mbps the total workload reached 6Mbps and 10Mbps. In order to evaluate the sole effect of the MAC protocol without any additional deficiencies imposed by the PHY layer, the highest capacity modulation is considered (64QAM3/4) which is shown that can sustain the imposed workload.

In figure 12 the mean packet delay measurements are depicted.
There are two approaches in order to analyze this figure. The first one is based upon the model utilized. In this case we compare the black with the blue and the orange with the ping graphs and the same overall conclusions can be drawn. That is, that the proposed model does impose some delay increment, which is of course expected since data are retransmitted in order to reach their final destination. But the important attribute is that this increase remains steady independent of the number of concurrent data flows existing in the network. That makes the network behavior deterministic when enabling the RS node which is probably the most important feature of a network.

The second approach is based upon the per flow data rate (and therefore the actual overall transmission rate). It is interesting that the 0.6Mbps measurements are more affected by the increase of the number of concurrent data flows, as opposed to 1Mbps measurements where although an increase exists it can be considered negligible (note the slope of the orange or ping graphs).

As far as the successfully transmitted packet measurements are concerned there are three major observations that should be mentioned: Firstly as expected the actual number of successfully transmitted packets is considerably more when we assume 1Mbps generators. Additionally the increase rate, relative to the number of concurrent data flows, is also higher for the 1Mbps generators (this is depicted by the gradient of the graphs). However the most important observation that has to do with the comparison of the B2BRS model as opposed to the default model is that the network capacity is not affected at all. Indeed as it is clearly shown the graphs are almost identical.

6 Conclusions

This paper focuses on wireless metropolitan area networks and more specifically in enhancing the IEEE 802.16 protocol providing relaying capabilities. Such functionality can be very useful to either extending the coverage areas or enhancing network capacity through cooperative communication techniques. Relay station is the key entity for such extension and thus a respective model is proposed. The proposed approach utilizes true sectoring capabilities and thus provides a simple yet efficient model. Some of the most important advantages of this concept are: provisioning of maximum degree of backward compatibility with standard compliant BS, SS nodes, true sectoring technology is available, spatial reuse is easily implementable. Through implementation of the model and respective evaluation it is shown that the proposed scheme is viable and worth further investigation. Additionally MAC and PHY SAP are identified as two very important research areas affected by the proposed model.

References


