Advanced Techniques for Improving the QoS of the WiMAX Cell Edge User

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Abstract — This paper discusses two of the advanced techniques, Fractional Frequency Reuse (FFR) and Multi-hop Relay (MR), available to the WiMAX network operator for improving the Quality of Service (QoS) for the cell edge user. The benefits of FFR are shown as reductions of the interference levels, while the benefits of MR are shown as improvements in coverage and signal quality. The corresponding results have been obtained through analytical studies and network planning exercises and are supported by system level simulations.

Index Terms — FFR, Interference margin, Multi-hop Relay, OFDMA, WiMAX

I. INTRODUCTION

The IEEE 802.16e standard [1] is the base-line for mobile WiMAX technology, which is facilitating mobile, broadband wireless access at very high QoS (Quality of Service) levels. To enable higher data throughput and better scalability, the 802.16e standard utilizes OFDMA (Orthogonal Frequency Division Multiple Access), where different users are multiplexed with time/ frequency resource allocations on the same transmission frame. Also 802.16e allows the very aggressive frequency reuse=1 planning for adjacent cells/ sectors. While this can improve the overall network throughput, the users near the cell edge will experience unacceptable levels of interference. Although the 802.16e standards provide random sub-channelisation schemes (PUSC, FUSC) to randomize the collisions of same time/ frequency resources, their impact diminishes once the full spectrum of frequencies are utilized in the transmission frame.

The WiMAX standard is pledging to provide ubiquitous, seamless broadband coverage, so maintaining a high QoS at the cell edge is a critical issue. Two of the WiMAX features, namely Fractional Frequency Reuse (FFR) and Multi-hop Relay (MR) that can facilitate a high QoS at the cell edge are discussed in this paper. In FFR, the users at the cell edge operate on a sub-frame zone with a fraction of all available sub-channels, while the inner cell users operate on a zone with all sub-channels available [2]. Usually, the cell edge users are operated with frequency reuse=3 (called the R3) zone and the inner cell users are operated in a R1 sub-frame zone. With MR (which is still in development through the 802.16j work group [3]) a relay station will be operated nearer to the cell edge with some of the resources dedicated to the cell edge users.

In this paper we illustrate the benefits of FFR and MR schemes through analytical studies and system level simulation results. In section II, the impact of FFR is shown as a reduction in the interference margins (I_m). The results from an analytical study and collaborative results from our System Level Simulator are presented. The Multi-hop relay (MR) concept is described in section III, with analytical results of a planning exercise with Relays. The conclusions and further work planned in this area are presented in section IV.

II. APPLICATION OF FRACTIONAL FREQUENCY REUSE

A. The FFR Concept

The FFR concept can be theoretically explained as excluding the cell edge users from the frequency reuse 1 (R1) operation and assigning them only a sub-set of the available sub-channels. This is illustrated in Figure 1 (from [2]) below, where F_A, F_B and F_C are different sets of sub-channels within the available sub-channels. In this configuration, the full load frequency reuse 1 operation is maintained for cell center users to maximize spectral efficiency, while fractional frequency reuse is employed for cell edge users by using R3 operation. Also shown is the transmission frame structure with time and frequency resource allocations for the R1 and R3 zones. The FCH/MAP part provides sub-channel allocation information, which allows the users to locate their resource block within the frame. Additionally, the FCH/MAP part carries other signaling such as the zone switch information elements, which indicate switching points between the R1 and R3 zones.
R1 and R3 operations (known as R1 and R3 zones) within the sub-frames. These have common boundaries for all the cells/sectors operated in the network, so there will be no inter-zone interference on R1 and R3. One advanced concept is to dynamically vary this zone boundary (across the network) depending on user behaviour and cell loading. However we have not considered this in our current study, where the zone sizes are kept fixed throughout the simulations.

B. Analytical calculations of Interference margins

With the interference margins \( I_m \), the interference power is defined as a ‘noise rise’ over the noise floor of the receiver [4]. Thus \( I_m \) is defined as the difference between SNR and SINR in logarithmic (dB) terms or as the following ratio in linear power terms.

\[
I_m = 10 \log \left( \frac{N + I}{N} \right)
\]

Where \( N \) is the thermal noise power and \( I \) accounts for the interference power.

With increasing cell loading factor (i.e. more users becoming active in a cell), the interference power increases while the noise power remains the same. The interference is generated from collisions of the same time/ frequency resource in adjacent cells. A detailed analytical study of this type of interference was carried out in [5] and the resulting values for \( I_m \) were derived. The uplink (UL) interference margins against the loading factor for different FFR formulations are shown below in Figure 2. The performance at the cell edge is considered, which is the worst case scenario in terms of interference effects. A larger zone size for R1 use would mean a smaller zone for the R3 users and hence fewer users in R3. The users are assumed to be uniformly distributed in the cell.

The average interference margins for the downlink are plotted below in Figure 3.

In the downlink, the interference margins reduce substantially when the full reuse 1 schemes are replaced with the FFR schemes. With reducing R1 zone sizes (or increasing R3 zone sizes) the interference margins drop down further. The results show that the averaged interference margins can be controlled by introducing FFR and adjusting the R3 zone sizes accordingly. Thus FFR is an effective tool in managing the interference levels at cell edge. This improvement in interference margins at cell edge directly translates to an improvement in cell edge QoS.

The interference margins for the uplink show a smooth, proportional increase with the cell loading factor. For the downlink, the interference margins jump up to a maximum value and thereafter remain at that plateau after around 30% of cell loading. This difference arises from the manner the UL and DL sub-frames are loaded. In the UL, the mobile station wants to transmit as low power as possible, so its data burst is concentrated on to a single sub-channel and the burst spans the whole of the time frame. Thus the 100% occupancy of the frame (i.e. 100% collisions) occurs when the UL sub-frame is fully loaded. This generates the maximum interference margins at full cell loading. However in the downlink, the base station does not have such power constraints. It will first fill-up all the sub-carriers and then move onto the next time slot. Thus the 100% collisions will occur every time the whole of sub-carriers are utilized in each of the time slots. This is reflected in the manner the interference margins reaching the peak value repetitively. We have assumed the worst case scenario of only 2 slot (i.e. 2 symbols) assigned to each user in this example.

C. System Level Simulations

Extensive FFR simulation results obtained with a proprietary WiMAX System Level Simulator (SLS) have been presented in [6]. They confirm the above findings of the analytical analysis and show considerable SINR gains with FFR at the cell edge compared to the R1 only case. In particular, FFR obtains cell edge SINRs similar to the R3 only case, while the
cell capacity is similar to the R1 only case. In summary, the SLS results show that FFR significantly improves cell edge coverage, thereby resulting in a higher QoS for cell edge users.

III. APPLICATION OF MULTI-HOP RELAY

Multi-hop Relay is an emerging topic in the WiMAX community and it is provisioned in the 802.16j standards [7]. Many forms of Multi-hop Relay schemes are currently envisaged and the main features of different adaptations are described below.

A. The Multi-hop Relay Concept

The basic idea of a Multi-hop Relay network is to incorporate Relay stations (RS) in between the Base Station (BS) and some of the Mobile Stations (MS) whose coverage directly from the BS is poor. The ordinary BS is thus replaced by a Multi-hop Relay BS (MR-BS) and one or more RS are included in the set-up. There are many variations of the MR concept currently under consideration and the main variations are detailed below.

Depending on the scheduling of users, two types of RS are envisaged as centralized and de-centralized relays. In centralized relays the scheduling (ie. resource allocation) for the MS coming under the RS is determined at the MR-BS. In the de-centralized (or distributed) relays, the scheduling of the subordinate MSs is carried out by the RS with guidance from the MR-BS.

When an RS does the user scheduling (de-centralized Relay) it also generates a frame header and MAP messages for its subordinate users. This is known as a non-transparent Relay, as the subordinate MS is aware of the relay’s existence. In transparent relays, the MR-BS does the scheduling and transmits the frame headers and MAP messages to all MS. In effect only the data slots for the subordinate MS are transmitted by the RS and it is transparent to the MS. The frame headers and MAP messages are power boosted and repetition coded to propagate for larger distances, which makes this transparent RS scheme workable.

Another variation considered in the standards is the in-band and out-of-band Relays. With in-band relays, the RS-MS link utilizes the same frequency spectrum and time zone is allocated in the MR-BS to MS DL/UL sub-frame for this link. Out-of-band Relays make use of additional spectrum available to the operator and would have its own DL/UL sub-frames.

A further variation considered in the standards divides the Relays into decode-and-forward and amplify-and-forward mechanisms. The amplify-and-forward relays are essentially like analogue repeaters, which enhance the signal received from the MR-BS and forward it to the MS. In doing so the noise within the original signal is also amplified. The decode-and-forward relays would fully regenerate the signal from MR-BS and transmit it to the subordinate MS.

In this paper, we consider distributed relays with non-transparent operation. The relays are assumed to be operating in-band with the decode-and-forward functionality.

B. Deploying Relays for Coverage Enhancement/Extension

The model we consider in this paper is deployment of Relays for coverage extension and enhancement. There are a variety of scenarios that can be envisaged under this category. Some of the more common uses of Relays in this model are shown below in Figure 4.

![Figure 4: Deployment of Relays for Coverage enhancement/extension][1]

In all of these cases, the RS positioning and its height provides better accessibility to the MR-BS and the shadowed/isolated MS in turn has better view of the RS. One of the key benefits of deploying a RS rather than a pico/femto BS is that the RS does not require a backhauling facility. The RS is connected to the MR-BS via the relay link of the radio frame. RS heights and locations can vary as shown in Figure 4. Locating the RS on top of a lamp-post is one of the options widely considered for static RS deployment. The site hiring costs and planning permission constraints are expected to be considerably lower for this type of deployments.

C. Network Planning Results on Relay Deployment

The results presented in this section are based on a nominal cell planning exercise for a WiMAX network covering Central London. The Relay Deployment model is cell edge extension, as illustrated in Figure 5 below. In this hypothetical scenario, the single cell coverage is extended to 3 cells by the positioning of 3 RS at the original cell edge.
In the actual cell deployment, the coverage is not as even as above, due to uneven shadowing effects with local clutter and terrain. The coverage improvement with Relays in the actual cell planning scenario is shown below in Figure 6. This is an uplink coverage plot, obtained with the Planet EV [9] network planning software.

The area under review is the square marked with the yellow lines, which is around 30km² in area. The coverage gaps in this BS deployment have been filled with 18 Relay stations. It would have required 6 more BS sites and an altogether new deployment to cover this area only with 3 sector BS sites. The RS antenna height is taken as 10m, while the BS antenna height is 35m. The RS transmit power is at 27dBm, while the BS transmits at 43dBm power.

Different colours in Figure 6 show different modulation and coding schemes. The dark green is for ¾ 16QAM, the highest modulation and coding scheme possible in the uplink. The light green is for ½ 16QAM, yellow is for ¾ QPSK and red is for ½ QPSK.

The inclusion of Relays in-place of BS has retained the uplink coverage levels in this scenario. More-over it has brought dark-green patches of ¾ 16QAM coverage to the original cell edges of BS sites. This planning exercise was carried out on a 2-dimensional digital map, where as if a 3D map was utilized additional coverage holes could have been identified and the benefits of Relays could have been further illustrated.

In a detailed costing analysis on Relay deployment [10], it has been shown that the capital and operational cost of 3 Relay stations is comparable to a 3 sectored BS. Hence it can be argued that Relay deployment is both technically and economically feasible in WiMAX networks.

IV. CONCLUSIONS AND FURTHER WORK

This paper investigates the impacts of two advanced technologies, the Fractional Frequency Reuse (FFR) and Multi-hop Relay (MR) in improving the quality of service for the cell edge users. We analyse the benefits of FFR analytically and also through link level simulation results. Both of them point out that increasing the re-use 3 zone in FFR would reduce the interference margins, giving a better quality of service to the cell edge user. Thus FFR provides a mechanism to control the signal quality for the cell edge user through managing the interference margins.

The MR is still a developing concept in the WiMAX standards and we have detailed the many variations that are currently being assessed. We concentrate on cell edge extension with MR and illustrate through network planning results how the signal quality at cell edges can be improved with MR.

Further work is planned in this research area, to gain more insights into the interference margin behaviour through link level simulations. For this we need to control the cell loading factor more accurately. There are plans to develop the link level simulator to cover the uplink, thus we will be able to study the behaviour of uplink interference margins with FFR. We also plan to develop our network dimensioning and planning capabilities for Multi-hop Relay networks, which can bring out more specific results on signal quality for the cell edge user.

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REFERENCES

[3] IEEE 802.16j working group www.ieee802.org/16/relay


[8] IEEE 802.16 Broadband Wireless access working group- Harmonised contribution on 802.16j(Mobile Multi-hop Relay) Usage models, 2006-09-05
