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System-Level Analysis of Outer Loop Link Adaptation on Mobile WiMAX Systems

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***Abstract*— Link adaptation is a process of paramount importance to optimize the performance of wireless communication systems. However, standardization committees have not standardized link adaptation procedures in order to foster competitiveness among vendors. As a consequence, many research projects have been conducted on this field and several strategies have been presented and tested, mainly for High Speed Downlink Packet Access (HSDPA) and Long Term Evolution (LTE) systems. For mobile WiMAX systems (IEEE 802.16e standard) the use of approaches like outer loop link adaptation (OLLA) has not been reported as much as for other system technologies. In this context, this paper aims at providing a system-level analysis of OLLA applied to mobile WiMAX systems. We use a system-level simulator in order to assess the performance of OLLA in mobile WiMAX system.**

Keywords*— *Link adaptation, WiMAX 802.16e, system-level analysis

I. Introduction

Third Generation Partnership Project (3GPP) has been working intensively on the evolution of mobile networks [1]. The interest of researchers and engineers to improve the link adaptation procedures increases as soon as the specifications of third and fourth generation networks are released and they are highly motivated by the challenging throughput, delay and quality requirements imposed by such system technologies. Channel Quality Indicator (CQI) is an important mechanism to provide feedback regarding the downlink channel quality from the mobile station to the base station and then to adjust the modulation and coding schemes accordingly.

Mller et al. [2] presented an enhanced link adaptation mechanism for High Speed Downlink Packet Access (HSDPA) in UMTS, which takes the age of channel quality feedback information into account. They evaluated the results with a dynamic system simulator having the user speed of 3km/h, 18 sectors and the average number of users per cell of 10 and 30. The link adaptation based on CQI age was compared with the one without any age information for different power delay profiles. Results showed a maximum gain of 45% in the sector throughput with the proposed link adaptation enhancement. The drawback of the method is that some parameters that are required to define the age are empirical and depend on information like the speed of the mobile station.

Martín-Sancristán et al. [3] evaluated link adaptation based on CQI for HSDPA on Node-B. Several CQI estimation strategies were tested, from the most simple one to a highly sophisticated procedure, like the averaging of the last *n* CQI reports and least mean squares prediction [4], respectively. It was shown how the selection of the strategy and the corresponding gains depend on the knowledge of the mobile station speed, and the implementation of such selection schemes may be a formidable challenge in real networks.

In [5] an analysis of imperfect link adaptation in next generation OFDMA cellular networks was performed. CQI delay and errors were taken into account. For pedestrian of an LTE system, significant performance degradation was observed when CQI delays are greater than 5ms. Imperfect CQI reports were also studied and it was shown how it can constitute a source of degradation.

The use of outer loop link adaptation in the link adaptation procedures when applied directly on Mobile WiMAX systems (IEEE 802.16e standard [6]) does not have many references in literature. Therefore, this paper focuses on a simulator-based system-level analysis in order to assess the effect of OLLA in mobile WiMAX system performance.

This paper is organized as follows. In section II link adaptation modeling and assumptions are presented. Section III describes the simulation environment, used models and key assumptions. Outer loop link adaptation analysis on mobile WiMAX system results are presented and discussed in Section IV. Finally, the conclusions are summarized in section V.

II. Link Adaptation Algorithms

The performance of wireless links depends on the conditions of the radio links. It means that performance indicators, such as block error ratio, throughput and delay, are not constant. In order to cope with the changing conditions of the radio links and provide minimum Quality-of-Service (QoS) for the services requested by the user terminals, the proper modulation and coding schemes have to be chosen. The mechanism that executes the process of dynamic adjust of these schemes is known as link adaptation. The focus of this work is mainly on strategies based on inner loop and outer loop link adaptations and they will be discussed in the next subsections.

A. Inner Loop Link Adaptation (ILLA)

The inner loop link adaptation method is based on Signal to Interference plus Noise Ratio (SINR) thresholds. In this method, a suitable SINR threshold is set for each supported modulation and coding scheme, which is defined in accordance with the capabilities of the mobile station. The algorithm chooses the highest scheme that fulfills the QoS requirements, depending on the measured SINR values. Link adaptation works separately for downlink and uplink, hence there are separate sets of downlink and uplink link adaptation thresholds. The more robust the modulation and coding scheme, the less throughput for a given SINR. Ideally, the maximum throughput is achieved when the performance of the link adaptation corresponds to the envelope of all modulation and coding schemes curves.

B. Outer Loop Link Adaptation (OLLA)

The main purpose of outer loop link adaptation is to keep the packet error rate (PER) at a given level by adjusting the adaptation thresholds dynamically, although the difference between the thresholds is kept the same. This is implemented by assigning the mobile station a specific offset, which is used to shift the estimated SINR value as described by the following equation:

$$SINR_{olla} = SINR - offset \quad (1)$$

The adjustment of the offset can be done based on reception of packets as follows [7], [8]:

- Correctly received packet reduces the offset by a given value of *stepDown* decibels:

$$offset = offset - stepDown \quad (2)$$

- Incorrectly received packet increases the offset by *stepUp* decibels:

$$offset = offset + stepUp \quad (3)$$

OLLA offset is adjusted for the system to achieve a given target packet error ratio (PER_t). The feedback of positive acknowledgment (ACK) messages notifies the base station of a correctly received packet and drives the offset towards more optimistic link adaptation thresholds. On the other hand, negative acknowledgment (NACK) messages drives the offset towards more conservative link adaptation thresholds. It can be shown that, for a given target packet error rate (PER_t), the step down is calculated as follows [7], [8]:

$$stepDown = \frac{stepUp}{(1/PER_t) - 1} \quad (4)$$

In our approach, OLLA is performed only when Hybrid ARQ (HARQ) scheme is enabled. It means that OLLA is not performed for non-HARQ packet data units. Besides, OLLA offset adjustment is done only for the first transmission of the HARQ packet data units.

III. Simulation Scenario

In order to evaluate the performance of the open loop link adaptation strategy described in the previous section, a dynamic system-level simulator was used. The simulator models a standard-compliant IEEE 802.16e WiMAX multi-cell and multi-user radio network including modeling of network layout, mobile station distribution and movement, radio environment, physical layer, medium access control layer with detailed implementation of radio resource management and ARQ algorithms, scheduling and access schemes, and traffic generation.

A. Network Topology and Deployment Scenario

The simulator models an outdoor macrocellular topology composed of homogeneous three-sectored hexagonal cells. The cellular grid is composed of 27 base stations and 75 hexagonal sectors, as illustrated in Figure 1.

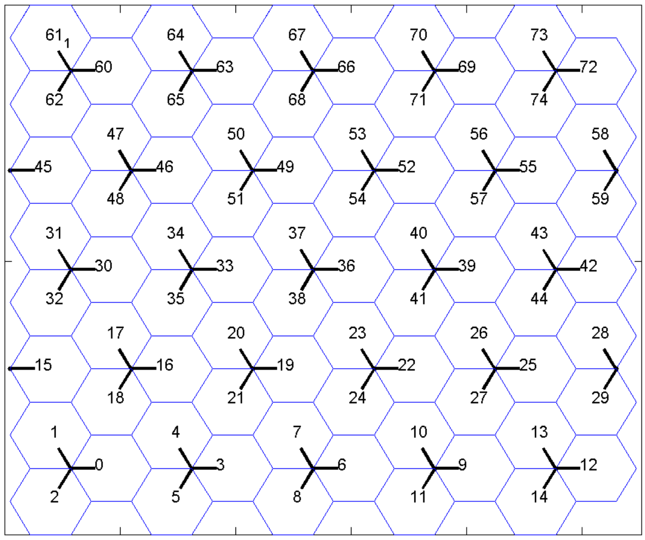

Fig. 1. Simulation Scenario

Frequency reuse 1-3-1 is employed, i.e. each base station has three sectors and all sectors are assigned the same radio-frequency channel. Table I lists the main parameters of the network topology used in the simulations.

TABLE I
Network Topology and Deployment

Parameters	Value
Num. of BSs	27
Num. of sectors per BS	3
Total number of sectors	75
Frequency reuse	1-3-1
BS-BS distance	1.5 km
Center frequency	2.5 GHz
Cell bandwidth	10 MHz
BS height	30 m
Num. of Tx/Rx antennas	1/2 (Maximum Ratio Combing)
Tx antenna pattern	70(-3dB), 20dB front/back ratio
Tx antenna gain	15 dBi
MS height	1.5 m
Number of Rx antennas	2
Rx antenna pattern	Omnidirectional
MS Noise Figure	8 dB

B. Propagation and Interference Models

The results presented in this paper assume an urban macro-cell environment for modeling the long-term characteristics of the wireless channel. This scenario is characterized by large cells, base station antennas above rooftop height and high transmit power. It uses the COST-231 Hata propagation model [9] for calculating the signal path losses. Shadowing is modeled as a lognormal random variable with zero mean and standard deviation equals to 8.0 dB. Shadowing correlation factor between sectors is equal to 1 for sectors of the same cell and 0.5 for sectors of different cells.

Fading characteristics of the channel are modeled using the same model for both information-bearing and interfering signals, which ensures that the effects of multipath propagation are captured for all relevant signals in the network. The parameters of the channel model correspond to the ITU power delay profiles and the Doppler spectrum according to [10], see also Table II.

TABLE II
PROPAGATION MODELS

Parameters	Value
Path loss model	COST-231 Hata
Lognormal shadowing	μ = 0 dB, σ = 8 dB
Shadowing correlation	100% inter-sector, 50% inter-BS
Channel model	ITU Pedestrian A (3 km/h)

C. OFDMA structure, Scheduler, HARQ and Link Adaptation

It is assumed that the mobile WiMAX TDD 5 ms frame is divided into downlink and uplink subframes, with the downlink subframe containing 24 (out of 47) data symbols. All base stations are assumed to be synchronized to maintain common frame start times and frame lengths, and they use the same type of permutations. PUSC permutations [11] are modeled in order to take advantage of its inherent frequency diversity. For the OFDMA parameters used in the system level simulation, the reader is referred to [11].

Mobile stations are created dynamically according to a specific arrival rate. Limits for maximum number of terminals in the network and per cell are defined in order to avoid overload in the simulations. A user distribution of 50% VoIP and 50% best effort (BE) is considered. VoIP-Jitter and FTP traffic models are used for VoIP and BE cases, respectively. Such models follow the approches reported in IEEE 802.16m Evaluation Methodology Document (EMD) [9].

The base station scheduler allocates the two-dimensional (time-frequency) OFDMA resources among active users. Resource allocation for the entire TDD frame is made in a Weighted Round-Robin (WRR) fashion with 3 times more scheduling opportunity for VoIP users, and the modulation and coding scheme (MCS) is chosen using the available channel quality indicator (CQI) from all mobile stations. HARQ is implemented using the stop-and wait protocol with multiple HARQ channels for every served mobile station. Chase Combining is used at the mobile station for successive HARQ retransmissions so that the data packets received with error are stored at the receiver and softly combined with following retransmissions. Link adaptation process is performed according to the model presented in the Section II. The main scheduler, HARQ and link adaptation parameters are presented in Table III.

TABLE III
SCHEDULER, HARQ AND LA PARAMETERS

Parameters	Value
Max number of terminals	1700
Max number of terminals per cell	100
DL/UL ratio in frame	24/23 [symbols/symbols]
CQI feedback period/Delay	1/0 [frames/frames]
Traffic Type	50% VoIP and 50% BE
Scheduling Algorithm	Weighted Round-Robin (WRR) with 3x more scheduling opportunity for VoIP users
HARQ Type	Chase Combining
Max number of HARQ Retrans.	3
HARQ channels	16
HARQ Retransmission Delay	1 frame
Initial Modulation	QPSK 1/2
Initial Modulation for broadcast	QPSK 1/2 REP 2
OLLA offset range	[-20 dB, +20 dB]
Initial OLLA offset	0.5 dB

D. Simulation methodology and physical layer abstraction

The simulation model is based on the methodology recommended in [11]. Perfect time and frequency synchronization is assumed. The effect of non-ideal channel estimation is taken into account in the physical layer abstraction. Mobile stations are assigned to the best-serving base station and sector according to their downlink received signal power (considering only path loss and shadow fading). Performance statistics are collected only for users served by the base station of the center cell.

A physical layer abstraction, based on link-level simulations, is employed to predict the physical layer performance at the system-level. The physical layer abstraction represents the wireless link transmission as a set of link-to-system curves which describe the dependence between the channel quality indicator and the code block error rate. In the physical layer abstraction of the dynamic simulator, the SINR is calculated for all mobile stations at each subcarrier for every transmission frame. The post-combined SINRs of all subcarriers are calculated depending on the antenna diversity scheme. Then, for each code block, the SINR are mapped into a block error rate following the Exponential Effective SINR Mapping (EESM) approach [9].

IV. RESULTS

In order to evaluate the impact of OLLA on the WiMAX network deployed in Section III, the following simulation campaign was performed:

- Only inner loop link adaptation enabled;
- Outer loop link adaptation enabled for the values of $PER_t \in \{10\%, 15\%, 20\%\}$ and $stepUp \in \{0.1, 0.2, 0.5\}$.

All statistics were collected in the center cell (sectors 36, 37 and 38 in Figure 1) in order to avoid edge effects. The values of PER_t and $stepUp$ were chosen based on some results presented in [7] and [8]. The simulation results are discussed with respect to the following performance indicators:

1) ***PER from 1st HARQ Transmission***: packet error rate collected only for the first HARQ transmission;
2) ***User Throughput / Downlink Frame Load***: average user throughput in Mbits/second normalized by the downlink frame load. Downlink frame load refers to downlink subframe utilization;
3) ***Spectral Efficiency / Sector / Downlink Frame Load***: sector spectral efficiency (PHY layer) normalized by the downlink frame load. This is needed to account for resources that are left unused because of scheduling issues.

Figure 2 shows the target packet error ratio and the achieved ratio for each case that was defined in the simulation campaign. Ideally, packet error ratio from the first HARQ transmission should be equal to the OLLA target packet error ratio (PER_t). However, it was observed that this is not the case when target ratio is low. The reason of the mismatch between the actual packet error ratio of the first HARQ transmission and the target ratio can be explained by the shape of the link-to-system curves, because they are quite steep compared to measurement accuracy especially at lower loads when interference can change in the data bursts quite a lot.

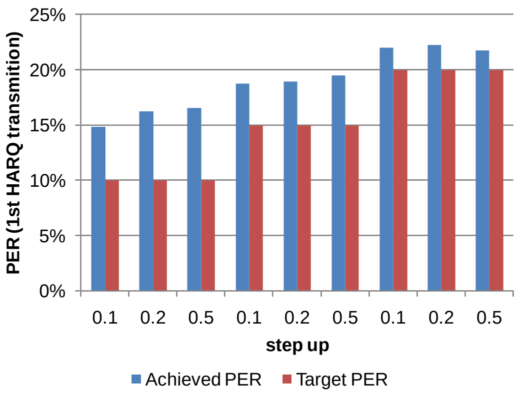

Fig. 2. Packet error ratio as a function of step up.

The gains provided by OLLA with respect to ILLA are shown in Figure 3 for the given target packet error ratios and step up values. We remark that spectral efficiency per sector and throughput per user are normalized by the average frame load. It is seen that one have to set different step up values for different target packet error ratios in order to squeeze higher capacity gains. Although the primary objective of OLLA is to provide the same Quality of Service (QoS) for all mobile stations, the results showed that it can also provide higher spectral efficiency with similar frame utilization.

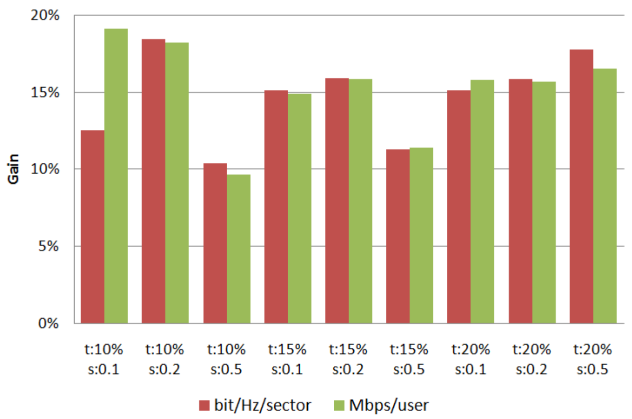

Fig. 3. Relative gains of OLLA for the given target packet error ratios and step up values.

Figure 4 shows a snapshot of the SINR and OLLA offset time-series. For this specific result it was assumed that the target packet error ratio is 20 %, OLLA step up is 0.1 dB. The figure shows the SINR traces of two mobile stations (MS 260 and MS 291) that are attached to the base station 37. It is clearly observed that between frames 6600 and 7200 the SINR values are very similar, but the offsets are different. Since the offsets are calculated based on the achieved packet error ratio, it means that the mobile stations may have been assigned different modulation and coding schemes as a consequence of, e.g. different link adaptation thresholds. If only ILLA was enabled in this simulation, the mobile stations would achieve different error ratios. It does not happen in this case, because OLLA is enabled and the offsets are calculated in order to equalize the QoS.

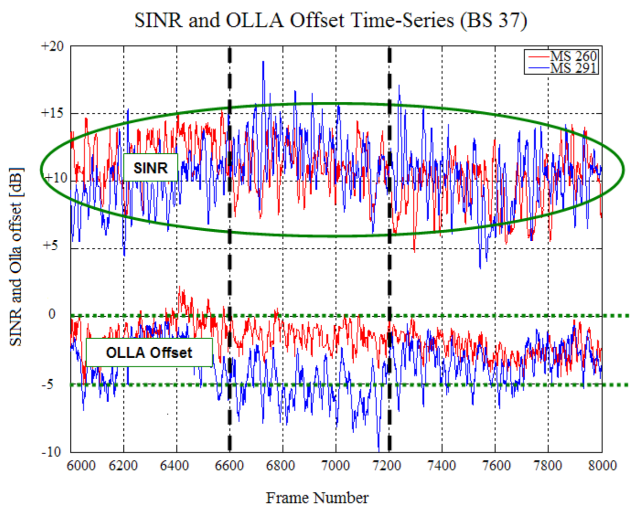

Fig. 4. OLLA offset time series.

Finally, Figure 5 shows the OLLA offset histogram. In the simulation steady state, there is a high density of OLLA offset values in the range [-5dB,+5dB] in accordance with the initial field trials of the feature.

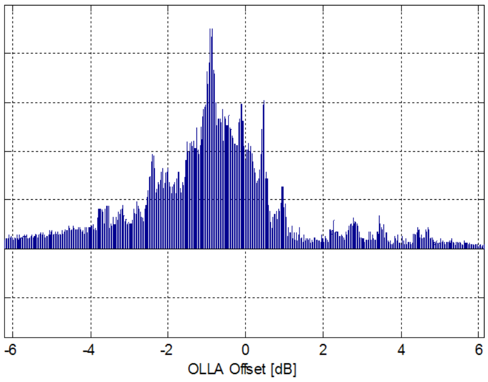

Fig. 5. OLLA offset histogram.

V. Conclusions

The employment of an outer loop link adaptation (OLLA) on mobile WiMAX system was analyzed based on results collected from a dynamic WiMAX system-level simulator. As expected, OLLA can provide some performance gains compared to a conventional strategy like the inner loop link adaptation (ILLA). It was observed that OLLA is able to track a given target packet error ratio, but the efficiency of this process is directly related to the choice of optimized values for the initial offset and link adaptation thresholds. Additionally, results showed the situation where OLLA is most needed, i.e. when mobile stations estimate similar SINR values, but they experience different quality of service as a consequence of different packet error ratios. In situations like this, OLLA assigns different offset values for the mobile stations and the system provides the same quality of service for all mobile stations. The impact of OLLA on real networks is left for further studies, but this feature has already presented interesting results that have shown performance improvements of the system.

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