Link Adaptation Thresholds for the IEEE 802.16 Base Station

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ABSTRACT

The IEEE 802.16 technology defines a number of modulation and coding schemes that the base station can use to achieve the best tradeoff between the spectrum efficiency and the resulting application level throughput. However, the 802.16 specification does not define any particular link level adaptation algorithm, neither does it specify the SNR thresholds to switch between modulation and coding schemes. In this paper we consider a link adaptation model and conduct a number of simulation runs to find transition thresholds for ARQ and HARQ retransmission mechanisms. All the simulations are done with the 802.16 extension for the NS-2 simulator.

Keywords

IEEE 802.16, AMC, ARQ, HARQ, NS-2.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Performance

1. INTRODUCTION

IEEE 802.16 is a standard for the wireless broadband access network [1] that can provide a high-speed wireless access to home and business subscribers. It supports applications and services with diverse Quality-of-Service (QoS) requirements. The core components of a 802.16 system are a subscriber station (SS) and a base station (BS). The BS and one or more SSs form a cell with a point-to-multipoint (PMP) structure. In this case, the BS controls the activity within a cell, resource allocations to achieve QoS and admission based on the network security mechanism.

Link adaptation plays one of the key roles in the 802.16 system. It chooses a suitable modulation and coding scheme (MCS) based on changing link conditions thus improving the spectrum efficiency [6, 11, 5]. It is usually the case that when the link condition is poor, bandwidth efficiency is sacrificed for robust communication between the transmitter and the receiver. Conversely, it is more resource efficiently to use an efficient MCS under good channel conditions. The IEEE 802.16 system [2] specifies different MCSs and message formats to deliver a broadband service. However, the specification does not provide a policy to select MCS for various link conditions, neither does it specify transition thresholds. The problem of an efficient link adaptation algorithm was tackled by a number of papers. However, in most cases authors assume that the transition thresholds are either known or calculated somehow by an outer control loop. In reality, finding optimal link adaptation thresholds is as important as the link adaptation algorithm itself because wrong thresholds can diminish any efficient approach.

In this paper, we tackle the problem of finding the transition thresholds for the link adaptation algorithm at the 802.16 base station. We consider separately several cases with ARQ and HARQ retransmission mechanisms. To find transition thresholds, we run simulation scenarios by using the 802.16 extension of the NS-2 simulator [10]. Since NS-2 provides a good support for higher layer protocols and applications, combining them with the 802.16 PHY and MAC allows to study the link adaptation from the user application performance point of view.

The rest of the article is organized as follows. Section II presents basics of the ARQ and HARQ mechanisms and the adaptive modulation and coding in IEEE 802.16. Section III considers several simulation cases to find the transition thresholds for ARQ and HARQ enabled connections. Finally, section IV concludes the article and outlines further research directions.

2. OVERVIEW OF ARQ, HARQ, AND AMC

2.1 ARQ

The automatic retransmission request (ARQ) is a mechanism by which the receiving end of a connection can request a retransmission of MAC PDU, generally as a result of having received it erroneously. If ARQ is enabled for a connection, then a PDU is considered to comprise a number of the ARQ blocks, each of which is of the same constant size except the final block which may be smaller. The ARQ block size is an ARQ connection parameter negotiated a sender and a receiver upon a connection setup. It is worth mentioning that an ARQ block is a logical entity – the ARQ

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block boundaries are not marked explicitly. The ARQ block sequence numbers in a PDU are determined based the ARQ block size, the overall PDU size, and the first block sequence number (BSN) stored in the PDU header. For exactly these reasons the ARQ block size is a constant parameter. Fig. 1 presents a data burst with two MAC PDU of the ARQ enabled connection: each PDU has a mandatory fragmentation subheader (FSH) with the first block sequence number and a mandatory CRC-32 field. Field sizes are given in bytes.

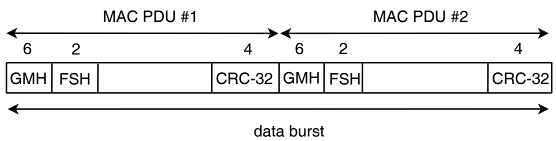

Figure 1: ARQ enabled MAC PDU.

To request a retransmission of blocks (NACK) or to indicate a successful reception of blocks (ACK), a connection uses ARQ block sequence numbers. In turn, the sequence numbers are exchanged by means of the ARQ feedback messages. It is up to the receiver, i.e., the sender of the ARQ feedbacks, when the ARQ feedback messages should be transmitted.

2.2 HARQ

Hybrid ARQ (HARQ) is a retransmission mechanism that is implemented at the physical layer together with FEC. It provides improved link performance over traditional ARQ at the cost of increased implementation complexity. The 802.16 system supports two HARQ schemes: chase combining (CC) and incremental redundancy (IR). In the case of the CC scheme, a retransmitted coded block is combined with the previously detected coded block and fed to the input of the FEC decoder. Combining the two received versions of the code block improves the chances of correctly decoding. In the IR scheme, only additional parity bits are sent during retransmissions. Regardless of a particular mode used, the HARQ sub-burst has a mandatory CRC-16 field, as shown in Fig. 2. In addition, the figure shows the per-PDU SN field that serves a purpose similar to the BSN of the ARQ mechanism.

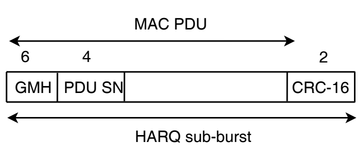

Figure 2: HARQ PDU.

The 802.16 standard supports a 16-channel stop and wait HARQ along with a variety of supported FEC codes. Doing multiple parallel channels of HARQ at a time can improve the throughput, since when one HARQ process is waiting for an acknowledgment, another process can use the channel to send some more data.

2.3 Adaptive Modulation and Coding

The 802.16 standard supports a variety of modulation and coding schemes and allows them to change on a burst-by-burst basis depending on channel conditions. Using the channel-quality feedback indicator, an SS can inform the base station with about the downlink channel quality. In the uplink direction, the base station can estimate the channel quality based on the received signal quality. The BS scheduler can take into account each SS uplink and downlink channel quality and assign a MCS that maximizes the throughput for the available signal-to-noise ratio (SNR).

Table 1: Modulation and coding schemes (CTC).

MCS	Max. FEC block size (slots)	Slot size (bytes)
QPSK 1/2	10	6
QPSK 3/4	6	9
16-QAM 1/2	5	12
16-QAM 3/4	3	18
64-QAM 1/2	3	18
64-QAM 2/3	2	24
64-QAM 3/4	2	27
64-QAM 5/6	2	30

In the downlink direction, QPSK, 16-QAM, and 64-QAM are the mandatory modulations, while 64-QAM is optional in the uplink direction. FEC coding using convolutional codes is mandatory. The standard also optionally supports convolutional turbo codes (CTC), block turbo codes (BTC), and low-density parity check codes (LDPC) at a variety of coding rates.[1] A total of 52 combinations of modulation and coding schemes are defined in [2] as burst profiles. In this paper we use the CTC MCSs because it is the only FEC block coding that is mandated by [3] for both ARQ and HARQ enabled data transmission. Table 1 presents FEC block and slot sizes of this coding scheme.

3. SIMULATION

This section presents simulation results for the link adaptation model and threshold to switch between MCSs. To run simulations, we have implemented the 802.16 MAC and PHY levels in the NS-2 simulator. It differs from other publicly available 802.16 modules by the significant number of supported features. The PHY level supports both OFDM and OFDMa. The MAC implementation contains all the main features of the IEEE 802.16 standard, such as downlink and uplink transmission, connections, MAC PDUs, packing and fragmentation, the contention and ranging periods, the MAC level management messages. The ARQ implementation supports the ARQ blocks, the ARQ transmission window, retransmission with rearrangement, all the ARQ feedback types, the prioritization of the ARQ feedbacks and retransmissions. All the related algorithms are presented in [9]. The HARQ implementation supports Type I, i.e., chase combining (CC) [2] with the HARQ ACK channel.

Fig. 3 shows the network structure we use in the simulation scenario. The simulation environment includes one wired node that is connected with a high-speed link to the BS. Such a choice is motivated by a desire to diminish any impact the wired medium may have on the simulation results. The simulation environment has also SSs, number of which varies depending on the simulation case. Each SS establishes the basic management connection to exchange

[1]The WiMAX Forum mobile system profile [3] also mandates the CTC FEC block coding.

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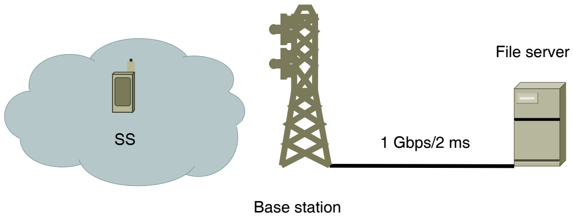

Figure 3: Network structure.

Table 2: 802.16 network parameters.

Parameter	Value
PHY	OFDMa
Bandwidth	10 MHz
FFT	1024
Cyclic prefix length	1/8
TTG+RTG	464 PS
Duplexing mode	TDD
Frames per second	200 (5 ms per frame)
OFDM symbols	47
DL/UL symbols	32/15
DL/UL subcarrier alloc.	DL PUSC/UL PUSC
DL/UL slots	480/175
DL/UL measurements	preamble/data burst
Channel report / interval	CQICH / 20ms
Channel measurements filter	EWMA, $\alpha = 0.25$
MAP MCS	QPSK1/2
Compressed MAP	ON
Ranging transm. opport.	2
Ranging backoff start/end	1/15
Request transm. opport.	8
Request backoff start/end	3/15
CDMA codes	256
ranging+periodic ranging	64
bandwidth request	192
handover	–
HARQ	Type I (CC)
HARQ channels	16
HARQ buffer size	2048 B (per channel)
HARQ shared buffer	ON
HARQ max. retransmissions	4
HARQ ACK delay	1 frame
PDU SN	ON
PDU SN type	long (2 bytes)
Fragmentation/packing	ON
PDU size	140 B (ARQ case) unlimited (HARQ)
CRC/ARQ	ON
ARQ feedback	standalone
ARQ feedback types	all
ARQ feedback interval	20 ms
ARQ block size	32 B
ARQ window	1024
ARQ block rearrangement	ON
ARQ deliver in order	ON
ARQ timers	
retry	100ms
block lifetime	500ms
Rx purge	500ms

the management messages with the BS. In addition, to exchange user data, an SS establishes one uplink and downlink BE connection. An SS hosts exactly one FTP-like application that *downloads* data from a wired node over the TCP protocol. The reason we choose such an application type is that it tries to send as much data as possible thus utilizing all the network resources. At the same time, the TCP protocol is very sensible to packet drops that can occur in the wireless part.

The 802.16 network parameters are presented in Table 2.[2] The PHY model is based on trace files gathered from the link level multi-cell simulations with the reuse 1-3-3 factor. There are uplink and downlink trace files that are chosen randomly by stations and are read from a random starting index. Then, MAC PDU error generation follows the IEEE 802.16m simulation methodology [4] and is based on the MAC PDU size and FEC BLER, whereas the latter is determined based on the current MCS and the SNR (see Fig. 4). HARQ PDU error generation also accounts for the HARQ retransmission gain.

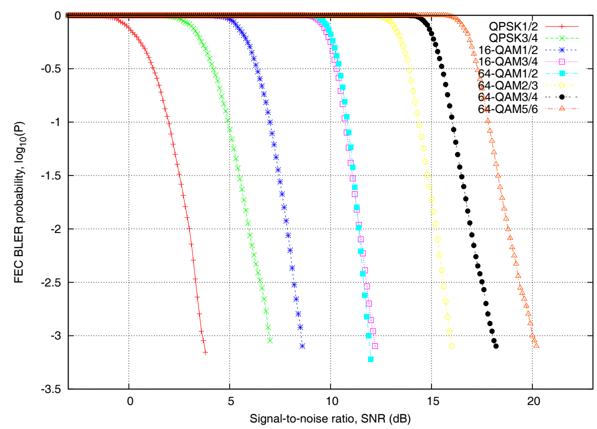

Figure 4: FEC BLER curves.

The BS reserves two transmission opportunities for the initial ranging purposes (as in real life, an SS has to join the network in our simulator) and eight transmission opportunities for the uplink bandwidth request contention resolution. Table 2 also presents the ARQ and HARQ parameters. All the parameters are the same except the MAC PDU size that depends on whether it is an ARQ or HARQ case. If HARQ is disabled, then it makes sense to have a limited PDU size due to a high drop probability of a large PDU [7]. If HARQ is enabled, then, from the MAC utilization point of view, it is more efficient to have one large PDU that spans the whole data burst.

The BS runs the scheduling algorithm, details of which are presented in [8]. In a few words, if there are only the BE connections, then the BS allocates resources fairly between the SSs based on their bandwidth request sizes and MCS. The BS HARQ scheduler always prioritize HARQ retransmissions over normal data.

The BS runs the link adaptation model that adapts both the uplink and downlink MCS based on observed SNR. Table 3 presents the link adaptation thresholds, i.e., the mini-

[2]These parameters conform the WiMAX Forum mobile system profile [3].

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mum channel performance that is necessary to enter a particular MCS. The same thresholds are used to leave a particular MCS and switch to a more robust one. While the BS adapts the MCS for the transport connections, all the downlink broadcast messages, such as DL-MAP and UL-MAP, are always encoded with a robust QPSK 1/2.

Table 3: Link adaptation thresholds.

MCS	Target FEC BLER					
	$10^{-0.5}$	10^{-1}	$10^{-1.5}$	10^{-2}	$10^{-2.5}$	10^{-3}
QPSK1/2	1.27	1.95	2.54	3	3.34	3.65
QPSK3/4	4.23	4.9	5.49	5.95	6.56	6.97
16-QAM1/2	6.39	7	7.47	7.86	8.2	8.55
16-QAM3/4	10.29	10.92	11.44	11.84	12.4	12.9
64-QAM1/2	10.69	11.32	11.89	12.4	12.9	13.35
64-QAM2/3	13.9	14.5	15	15.42	15.89	16.2
64-QAM3/4	15.55	16.15	16.69	17.19	17.69	18.22
64-QAM5/6	17.25	17.9	18.53	19.15	19.85	20.5

Each simulation run lasts for 10 seconds. It is enough to study transition thresholds and the behavior of the link adaptation model because it adapts MCS in every frame, i.e, every 5ms. Besides, the PHY traces contain 2,000 entries whereas each entry corresponds to a single frame. Thus, running longer simulations will not bring new results. However, each simulation case is repeated 10 times with different initial seed values. It instructs SSs to choose different starting entries within a trace file.

The actual FTP data transmission begins at the 1.5th second of the simulation run because first SSs have to enter the cell and register at the BS.

3.1 Simulation results

In this subsection we present the simulation results for different target FEC BLERs and the number of SSs. The SNR values for the target FEC BLER thresholds were taken from Table 3 and the number of SSs varies from 2 till 32. We use the total amount of transferred data as a performance indicator. Indeed, if the link adaptation model uses a right threshold then it should result in the best tradeoff between the spectrum efficiency and FEC BLER. It should be noted that we measure the amount of transferred data at the *application* level, i.e., after all MAC retransmissions and reassembly actions.

Fig. 5 presents the total amount of transmitted data in the downlink direction when connections use the ARQ mechanism. As a general trend, the more stations we serve in a single MAC frame, the less data they can transmit because of the increased signaling overhead. Furthermore, as can be seen from the figure, when there are a few data bursts per a frame, the optimal threshold corresponds to the target FEC BLER of $10^{-2.5}$. As the number of stations increases, the optimal threshold value becomes closer to 10^{-2}. The explanation is that if there are only a few large data bursts per a frame, then PDUs inside each data bursts are more vulnerable to channel errors because a significant amount of PDUs will be dropped if the channel quality declines suddenly. Conversely, if there is a number of smaller data bursts, then each of them can exploit a more extreme threshold to achieve a better spectrum efficiency.

Fig. 6 presents similar simulation results for a case when connections use the HARQ retransmission mechanism. Firstly, it is noticeable that HARQ is capable of transmitting more data in all case when compared to ARQ. Secondly, due to

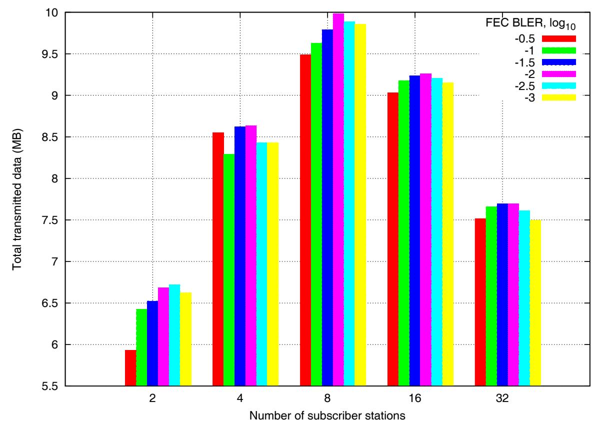

Figure 5: Total transferred data (ARQ enabled).

the HARQ retransmission gain, it is possible to rely upon more extreme transition thresholds thus achieving a better spectrum efficiency. Depending on the case, the optimal threshold varies between $10^{-2.5}$ and $10^{-1.5}$

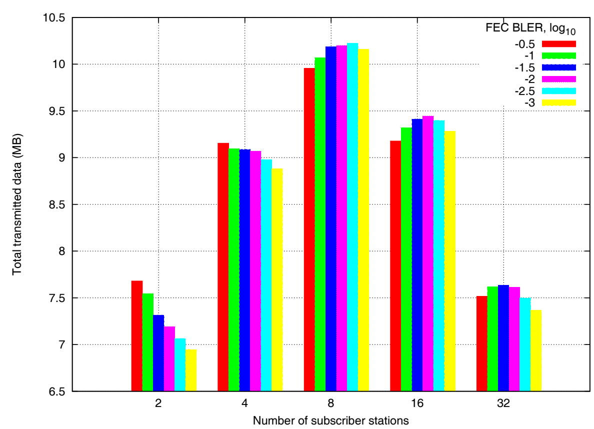

Figure 6: Total transferred data (HARQ enabled).

4. CONCLUSIONS

In this paper, we have analyzed the link adaptation model and MCS transition thresholds for the IEEE 802.16 base station. We have shown that the optimal transition threshold for the ARQ connections is between 10^{-2} and $10^{-2.5}$, while for the HARQ enabled connections it is from $10^{-1.5}$ to 10^{-2}. It fully conforms to the theoretical expectations that HARQ should outperform ARQ due to the retransmission gain. An interesting outcome of the paper is that the optimal thresholds depend on the number of data bursts per a frame. It requires a coordinated functioning between the BS link adaptation model and the scheduler. Even though we considered only the CTC coding, the obtained results can be applied to any coding schemes supported by 802.16 systems because we use present threshold values measured in target FEC BLER, not in absolute SNR values.

The simulations were done in the NS-2 802.16 extension that has all the PHY, MAC, scheduling, and upper level features. We presented that it is possible to study wireless

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MAC and PHY issues with packet level simulators, such as NS-2. Furthermore, obtained results can be reused in other wireless technologies implemented for NS-2 because link adaptation is a key component of any wireless system.

Our future research will aim at combining the theoretical link adaptation models proposed by other researchers with the results obtained by means of simulations. Besides, a full featured link adaptation model should account for other parameters, such as standard deviation of the channel measurements, the channel report intensity, and the burst size.

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