Impact of Adaptive Downlink-Uplink Channel Split Ratio and Cyclic Prefix on WiMAX Network

Deepika Chaubey, Mohit Pant, Vineeta Choudhary

***Abstract*—In this paper, we study the determination of down-link (DL) and uplink (UL) channel split ratio for Time Division Duplex (TDD)-based IEEE 802.16 (WiMAX) wireless networks. In a TDD system, uplink and downlink transmissions share the same frequency at different time intervals. The TDD framing in WiMAX is adaptive in the sense that the downlink to uplink bandwidth ratio may vary with time.**

At physical layer WiMax uses orthogonal frequency division multiple access technique in wireless communication. OFDM delivers a wireless signal much farther with less interference. Cyclic Prefix (CP) is used to combat intersymbol inter-ference (ISI) and intercarrier interference (ICI) introduced by the multipath fading channel.

WiMax provides high-speed data access to the Internet where the transmission control protocol (TCP) is the core transport protocol.

In particular, we investigate the dependence of the aggregate throughput and goodput of TCP on factors such as DL:UL ratio, Cyclic Prefix, frame duration, modulation and coding scheme and offered loads. It finds that these factors affect TCP performance by exacerbating the bandwidth asymmetry inherent to the MAC layer and cyclic prefix inherent to the Physical layer.

Index Terms **-IEEE 802.16, Media Access Control (MAC), MAP, TCP throughput & goodput, Cyclic Prefix, Frame duration, DL:UL ratio.**

I. Introduction

All manuscripts IEEE 802.16 (WiMAX) is an emerging last mile technology for broadband wireless access [1]–[3]. A typical IEEE 802.16 network consists of base stations (BSs) and subscriber stations (SSs). The IEEE 802.16 standard [4] specifies two modes of operations, namely, point-to-multipoint (PMP) and mesh (optional) modes. In the PMP mode, the transmissions from SSs to BS are centrally coordinated by the BS, and the transmissions in both directions take place directly between BS and SSs. In the mesh mode, the transmissions can occur between SSs, and can also be relayed via other SSs. IEEE 802.16 supports both Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In an FDD system, the uplink and downlink channels are located on separate frequencies and data can be transmitted simultaneously. With TDD, the uplink and downlink transmissions usually share the same frequency at different time intervals. In this paper, we focus only on TDD system. In TDD, downlink (DL) and uplink (UL) transmissions use the same frequency, but occur at different times during the frame duration (Fig. 1).

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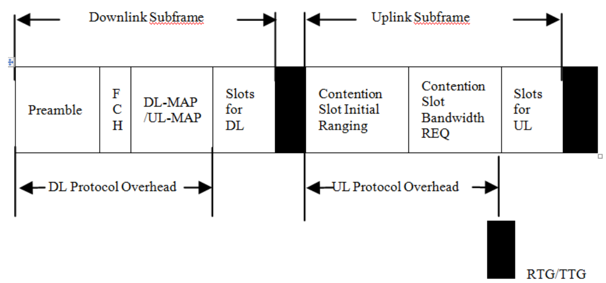

Fig. 1 IEEE 802.16 TDD frame and protocol overheads

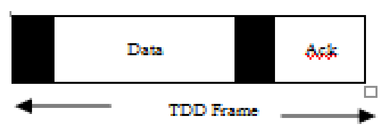

Fig. 2 Downloading frame

The first portion of the frame is called downlink subframe and is used for transmission from the base station (BS) to subscriber stations (SSs). The second portion of the frame is called uplink frame and is used for transmission frame SSs to Base station. The ratio of the subframes, henceforth called DL:UL ratio, can be adaptive. In PMP, both downlink and uplink transmissions are controlled by the BS via downlink MAP (DL-MAP) and uplink MAP (UL-MAP) messages respectively (Fig. 1). The MAP messages define the allocation start times and profiles to be used by each burst and are sent at the beginning of each frame.

In WiMAX, the DL:UL ratio or Downlink-Uplink channel split ratio plays an important role in the bandwidth asymmetry. In download-only situations, TCP packets are sent in the downlink subframe, and ACKs returned in the uplink subframe (Fig. 2). The protocol overheads also contribute to the asymmetry by consuming a significant portion of the bandwidth (Fig. 1, Fig. 2).

In WiMAX for best-effort class of service where TCP typically operates, the uplink access mechanism is mainly based on a request-grant process. Before an SS can send traffic, it must first contend with other SSs within the radio range for bandwidth requests. A collision may occur when two SSs request at the same time, in which case an algorithm is invoked based on truncated binary exponential backoff scheme. Even if the bandwidth request succeeds, the SS still needs to receive the grant prior to sending any data. Therefore, there are bandwidth waste (to bandwidth request), delays (due to the request-grant process) and unpredictability (due to backoff) in uplink resource access. On the contrary, the bandwidth on the downlink is fully controlled by the BS which schedules transmissions without much overhead, loss and delay.

WiMax uses orthogonal frequency division multiple access technique in wireless communication. Orthogonal frequency division multiple access (OFDM) is what puts the max in WiMAX. OFDM delivers a wireless signal much farther with less interference. In OFDM cyclic prefix is used to combat intersymbol inter-ference (ISI) and intercarrier interference (ICI) introduced by the multipath fading channel. Cyclic prefix adds additional bits at the transmitter end. The receiver removes these additional bits. The Cyclic Prefix is used to reduce the effect of fading in the channel and improve the performance of the channel and also improve Bit Error Rate. Cyclic prefix acts as a buffer region where delayed information from the previous symbols can get stored. Transmission of cyclic prefix reduces the data rate, the system designers will want to minimize the cyclic prefix duration. Typically, cyclic prefix duration is determined by the expected duration of the multipath channel in the operating environment. In the simulation model data is modulated and then Cyclic Prefix is added to it to reduce the effect of fading and to give sufficient time to the receiver for storage of signal. The purpose of this paper is to investigate, through simulation, the dependence of TCP performance on several WiMAX design/operating parameters such as frame duration, DL:UL channel split ratio, offered loads, modulation and coding schemes and Cyclic Prefix. Simulation results show that the above parameters impact the aggregate TCP throughput and goodput performance by exacerbating the network asymmetry at the MAC layer and cyclic prefix at the Physical layer.

The rest of the paper is structured as follows. The next section discusses related work in the literature. The system model for the investigation is introduced in Section III. In Section IV, simulation scenarios are presented and the results are discussed. Finally, we present our conclusions in Section V.

II. Related Work

Many researchers have presented various mechanisms with the objective of transporting data with different quality of service (QoS) requirements over WiMAX networks. Most of the work focus on defining the components such as scheduling which are intentionally left open in the standard for reasons of implementation flexibility [5]–[7]. Others focus on optimizing the bandwidth request-grant mechanism ratified by the standard but which need to be tuned for TCP-traffic because of bandwidth waste, delay, collision and backoff [8]– [10]. There are only few works studying the impact of network asymmetry on transport protocol performance. Chiang et al. [11] propose a DL:UL ratio that is dynamically adapted in response to actual number of FTP flows admitted within the system. Their simulative-analytic study focuses on the bandwidth asymmetry adaptation. They derive expressions for the asymmetry ratios for both uplink and downlink using longlived TCP flows. They conclude that both ratios should be 1 to avoid asymmetries and maximize aggregated throughput at the WiMAX access network in simultaneous two-way transfers. Wu et al. [12] suggest the use of smart ACKing schemes originally proposed in [13] to improve TCP performance in bandwidth asymmetric networks. The main principle of these schemes is to reduce the frequency of ACKs in the reverse bottleneck link. In [14], the authors propose a spectrally efficient modulation and coding scheme together with Automatic Repeat request (ARQ) for the data channel, and an expensive (robust) MCS in the reverse channel for ACKs. According to them, an ACK loss is highly undesirable. Their justification is that ACK losses contributes to the TCP-sender burstiness, an increased RTT (due to the cost induced by the bandwidth request mechanism), and an unfair augmentation of the packet loss rate (due to its relatively small size). This work complements these works by investigating the dependence of TCP performance not only on bandwidth asymmetry but also on other WiMAX design/operating parameters that impact the network asymmetry.

III. System Model

This section, present the system model used in the investigation. The network setup is shown by Fig. 3.

A. *Simulation Environment*

The investigation was through simulation. The simulation platform is *ns-2* and the WiMAX module is from the National Institute of Standards and Technology (NIST) [15]. The simulations parameters are summarized in Table I.

Ideal channel conditions are assumed. For the following scenarios it has been evaluate the performance of long-lived TCP flows. Each subscriber station holds a single downloading or uploading TCP flow.

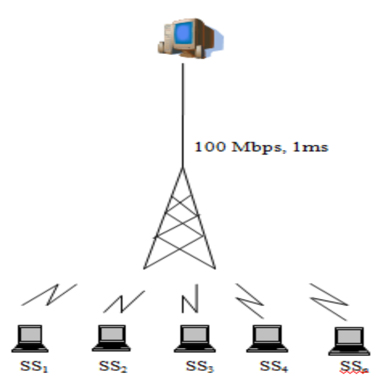

Fig. 3 The network setup

TABLE I Simulation Parameters

WiMAX and OFDM Parameters	
Channel bandwidth	
Frame duration	7 MHz
Modulation & Coding	5ms,10ms
	7=64QAM 3/4,6= 64QAM 2/3,5=16QAM 3/4,4=16QAM 1/2,3=QPSK 3/4,2=QPSK 1/2,1= BPSK1/2
Cyclic prefix	

Contention size	0.0625ms,0.125ms,0.25ms,0.8ms,1.0ms,1.2ms,1.5ms 5
Traffic Source and Other Parameters	
TCP version TCP segment size Delayed ACK factor TCP start time Simulation duration	New Reno 960 Bytes 2 1s 300s

B. *Performance Metrics*

It has been study the performance by means of two metrics:

- *Throughput* that measures the amount of raw bytes sent by a source.
- *Goodput* that measures bytes that are sent and successfully acknowledged.

IV. Simulation Result

This section, present the simulation scenarios and discuss the results obtained. Several scenarios are considered to highlight the effects of offered load, modulation and coding schemes, frame duration, and two-way transfers on aggregate TCP performance.

A. *Scenario 1: Effect of Load*

In the first scenario, all SSs download FTP traffic from the server. It has been study the impact of offered load (i.e. number of SSs) on aggregate throughputs and goodputs of the system for each DL:UL ratio by considering cyclic prefix 0.0625ms. The results are presented in Fig. 4 & 5.

As can be seen, aggregate throughput increases with offered loads and DL:UL ratios. The system is more utilized with more downloading SSs (loads). However, the system resources are finite, and when its capacity is reached new connection cannot be admitted. For DL:UL ratio 0.5, maximum throughput is around 10.5Mbps and this DL:UL ratio continuously decreases throughput for more than 25 downloading nodes (see Fig. 4). Increasing DL:UL ratio increases performance and admission capacity. For DL:UL ratio 0.80 there is big gap between throughput and goodput (see Fig. 5). The uplink bandwidth is too small in this case only 0.20 which is used by many SSs for returning ACKs of receiving packets. Since the lack of uplink bandwidth all ACKs are not send successfully to the sender. In result of this sender retransmit the packets which decrease the actual throughput (goodput).

It is also observed that for DL:UL ratio 0.80 initially for less number of nodes the throughput is higher than the other DL:UL ratio's throughputs. The reason behind this is continuous increment in TCP window. The 0.80 offer maximum possible slots for data in DL, and 0.20 slots for ACK in the UL. Initially 0.20 UL is enough for less number of uploading nodes which increases congestion window but as well as number of uploading nodes are increases 0.20 is not enough for uploading. Result of this is retransmission of TCP

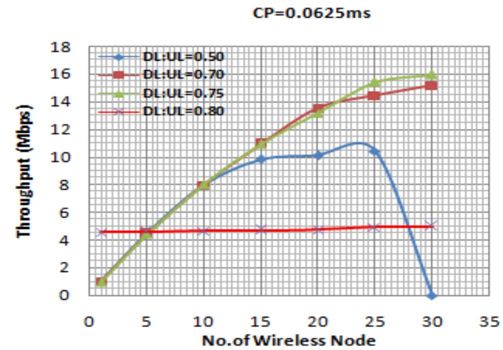

Fig. 4 The Aggregate Throughputs
(All wireless nodes (SSs) are downloading)

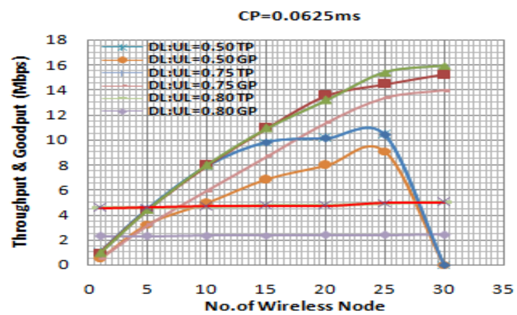

Fig. 5 The Aggregate Throughput & Goodput
(All wireless nodes (SSs) are downloading)

B. *Scenario 2: Effect of Modulation and Coding Scheme*

This study considers the same radio conditions and hence the same modulation and coding schemes (MCS) for all SSs. In this section, we change the MCS for all SSs. The offered load is constant with 15 downloading SSs. It has been plot the throughputs and goodput against MCS for fixed DL:UL ratio 0.5 in Fig. 6 and Fig. 7.

It is observed that for higher order modulation coding scheme, the value of throughput and goodput is maximum. Higher order modulations like QAM for increased throughput and goodput.

For cyclic prefix 0.0625ms, maximum throughput is around 9.80Mbps for 64QAM 3/4 modulation coding scheme which is higher order modulation coding scheme, 8.3Mbps for cyclic prefix 0.25ms and 5.4Mbps for cyclic prefix 0.8ms respectively.

For cyclic prefix 0.0625ms, maximum, goodput is around 4.82Mbps for 64QAM 3/4 modulation coding scheme, 4.09Mbps for cyclic prefix 0.125ms and 2.68Mbps for cyclic prefix 0.8ms respectively.

The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions. As the range increases, modulation step down to lower modulations (in other words, BPSK), but as you are closer you can utilize higher order modulations like QAM for increased throughput.

It is also observed that for higher cyclic prefix values and lower modulation coding scheme, coverage area that would be covered by the signal is increases but throughput and goodput are decreases.

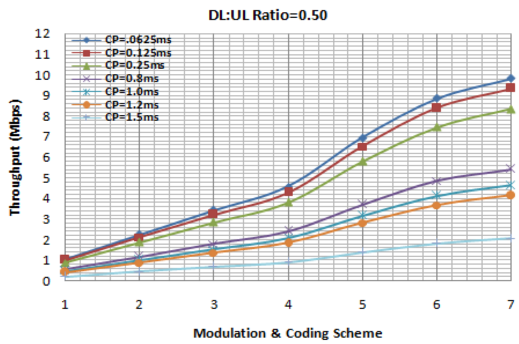

Fig. 6 Aggregate throughput for MCS
(For 15 downloading wireless nodes)

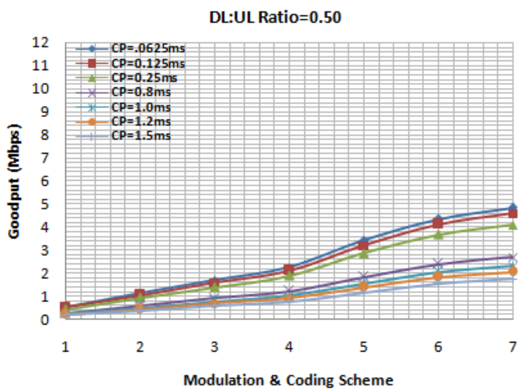

Fig. 7 Aggregate goodput for MCS
(For 15 downloading wireless nodes)

C. *Scenario 3: Effect of Frame Duration*

It has double the frame size to 10ms. The offered load is constant with 25 downloading SSs. It has been plot the throughputs against different DL:UL ratios. Simulation results are shown in Fig. 8.

As can be seen, aggregate throughput increases with DL:UL ratios. It is observed that if frame duration increases the throughput is decreases. The aggregate throughput at DL:UL ratio 0.75 of 10 ms frame is 9.8Mbps and for 5 ms frame aggregate throughput is 15.8Mbps.

It is also observed that for DL:UL ratio 0.80 the throughput is 5Mbps & 3.2Mbps for 5ms & 10ms frame durations respectively. This fall in throughput is due to greater asymmetry in both frame durations.

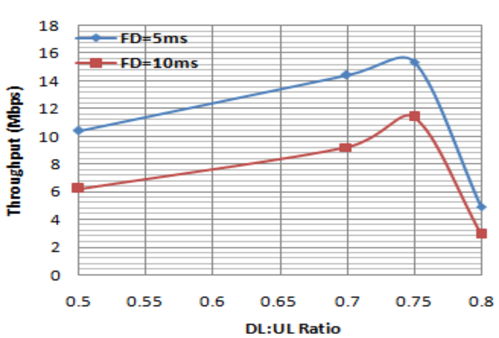

Fig. 8 Aggregate throughput for Different DL: UL Ratio
(For 25 downloading wireless nodes)

D. *Scenario 4: Effect of Cyclic Prefix & DL:UL Ratio*

In this section it has been analyze the performance of TCP in terms of throughput by considering cyclic prefix and DL:UL ratio simultaneously. The offered load is constant with 25 downloading SSs. Simulation results are shown in Fig. 9.

Cyclic Prefix is inherent to the Physical layer to combat intersymbol inter-ference (ISI) and intercarrier interference (ICI) introduced by the multipath fading channel. cyclic prefix is added to reduce the effect of fading and to give sufficient time to the receiver for storage of signal[2-7]. As distance increase fading is more and signal strength is going low. For this higher value of cyclic prefix is consider because large cyclic prefix means large time gap between two frames. Large value gives extra time to receive signal from multipath signals.

It is observed that for large value of cyclic prefix throughput is decreases.

The bandwidth asymmetry inherent to the MAC layer in WiMax . In WiMAX, the DL:UL ratio or Downlink-Uplink channel split ratio plays an important role in the bandwidth asymmetry.

It is observed that the higher value of cyclic prefix does not support the greater asymmetry. For higher value of cyclic prefix support lower DL:UL ratio. For cyclic prefix 1.5ms the value of DL:UL ratio is 0.53 and for cyclic prefix 1.2 the value of DL:UL ratio is 0.58.

It is also observed that for each value of cyclic prefix there is a threshold value of DL:UL ratio. If DL:UL ratio increases to this threshold values with respect to individual cyclic prefix than the throughput will be the zero. For cyclic prefix 1.5ms, 1.2ms and 1.0ms the threshold value of each DL:UL ratio is 0.53,0.58 and 0.63 respectively.

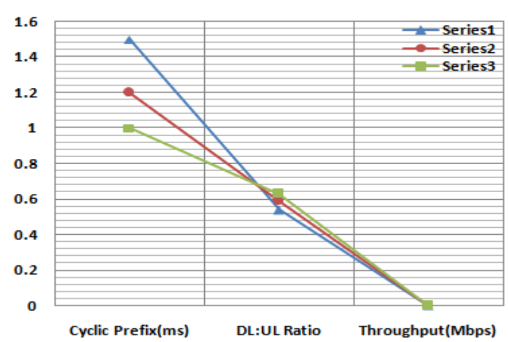

Fig. 9 Aggregate throughput for Different Cyclic Prefix & DL: UL Ratios
(For 25 downloading wireless nodes)

E. *Scenario 5: Maximum Throughput and Goodput w.r.t. Cyclic Prefix & DL:UL Ratio*

In this scenario, all SSs download FTP traffic from the server. The maximum value of throughput and goodput can achieve by changing the value of DL:UL size ratio for each Cyclic Prefix.

It is observed from Fig.10 for 30 downloading wireless nodes and cyclic prefix 0.0625ms we get maximum throughput and goodput which is 15.94Mbps and 7.63Mbps respectively at DL:UL ratio 0.75. It is also observed that for cyclic prefix

0.0625ms the value of best suited DL:UL size ratio is 0.75 in which we get maximum throughput and goodput.
For cyclic prefix 0.125ms the value of best suited DL:UL size ratio is also 0.75 in which maximum throughput is obtained.
From Fig 11 It is observed that for each value of Cyclic prefix there is value of best suited DL:UL size ratio on which it gives maximum throughput and goodput. For Cyclic Prefix 0.0625ms the value of best suited DL:UL size ratio is 0.75. For Cyclic prefix 0.125ms, 0.80ms,1.0ms, 1.2ms, and 1.5ms the value of best suited DL:UL size ratio is 0.75, 0.64, 0.62, 0.56, and 0.53 respectively.

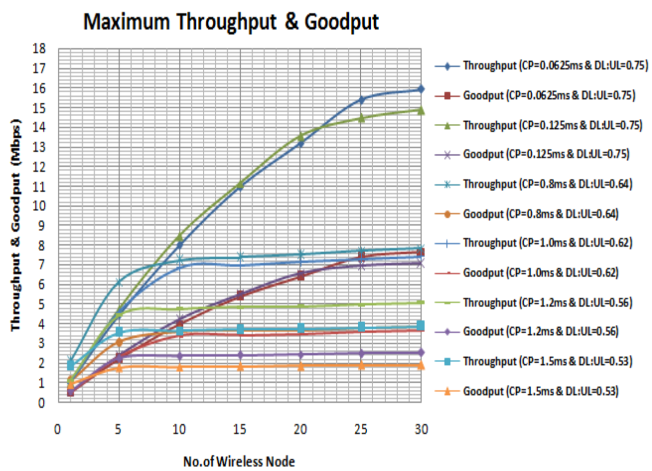

Fig. 10 The Aggregate Maximum Throughput and Goodput
(All wireless nodes (SSs) are downloading)

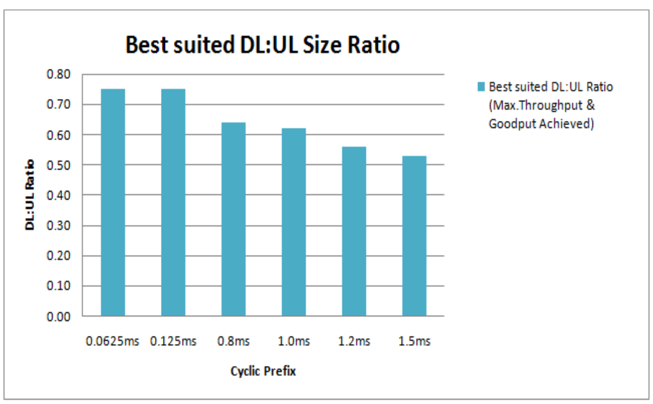

Fig. 11 The Best Suited DL:UL size ratio for different Cyclic Prefixes

V. Conclusion

In this paper, it has been investigated the impact of network asymmetry and cyclic prefix inherent in WiMAX network. Specifically, it has seen that TCP performance in terms of throughput and goodput depends on DL:UL ratio, frame duration, cyclic prefix, offered loads, and modulation and coding schemes. In downloading-only transfers, for instance, increasing the ratio improves the performance and admission capacity of the system. Increasing it beyond a certain threshold value, however, backfires as asymmetry develops in the system. It is concluded that Cyclic Prefix is key player in WiMAX Network.

It is observed that the modulation and coding scheme and Cyclic Prefix affect the performance of WiMAX network. The Cyclic Prefix play an important role to increase and decrease the throughput and goodput.

It is also observed that the for each cyclic prefix value there is some threshold value of DL:UL ratio at MAC layer. Above this threshold value throughput and goodput of TCP will be the zero.

It is observed that for each value of Cyclic prefix there is value of best suited DL:UL size ratio on which we get maximum throughput and goodput.

Finally the Cyclic Prefix 0.0625ms, DL:UL size ratio 0.75, and 64QAM_3_4 modulation coding scheme for 30 downloading nodes is good for better performance of WiMAX network.

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