Measurement and Analysis of World of Warcraft in Mobile WiMAX Networks

†Xiaofei Wang, †Hyunchul Kim, ♭Athanasios V. Vasilakos, †Ted "Taekyoung" Kwon,
†Yanghee Choi, §Sunghyun Choi, *Hanyoung Jang
†Multimedia & Mobile Comm. Lab., School of Computer Science & Engineering, Seoul National Univ., Korea
♭Dept. of Computer and Telecomm. Engineering, Univ. of Western Macedonia, Greece
§Multimedia & Wireless Networking Lab., School of Electrical Engineering and INMC, Seoul National Univ., Korea
*XRONet Corporation, Korea

***Abstract*—Online games have been played mainly over wired networks due to high speed links and capable desktop computers. The advances in mobile devices and ever increasing wireless link bandwidth motivate us to study whether players can enjoy online gaming over broadband wireless networks such as mobile WiMAX networks. In this paper we carry out the World of Warcraft (WoW) measurements via the mobile WiMAX networks and analysis the performance. We focus on two aspects: (1) application level packet dynamics such as RTT and jitter; (2) WiMAX link level statistics such as wireless link quality and handovers. We measure various scenarios for comprehensive analysis of WoW traffic and WiMAX link-layer characteristics. Finally we discuss how to improve the service quality of WiMAX online gaming.**

***Index Terms*—Measurement, analysis, online game, WiMAX.**

I. Introduction

Over the last decade, the online game has become one of the most popular and profitable applications on the Internet. So far people have enjoyed various gaming experiences in virtual worlds mostly over the wired Internet. Recently the Worldwide Interoperability for Microwave Access (WiMAX) [1] network based on IEEE 802.16(e) standard [2] has been gaining a lot of attention as IP-based wireless access networks for *mobile* users. Since the Wireless Local Area Networks (WLANs) have the limitation of mobility support, it is difficult for mobile users to play online games for a sufficient time over WLANs. In contrast, the WiMAX network supports handovers and mobility management within metropolitan coverage, thus it potentially provides continuous IP-compatible Internet services to mobile users.

The first successful WiMAX network was deployed and commercialized in Seoul, Korea, by Korea Telecom in 2006, and is referred to as Wireless Broadband (WiBro) [3]. For simplicity, we use WiMAX to denote the WiBro network access in the tests throughout this paper. The WiMAX adopts time division duplex between downlink and uplink, and for flexible bandwidth allocation among users, the Orthogonal Frequency Division Multiple Access is employed for multiple access. A Base Station (BS) offers an aggregate throughput of 30 to 50 Mbps theoretically and covers a radius of 1 to 5 km, supporting mobility up to 120 km/h. To keep the continuous Internet connectivity, when a Subscriber Station (SS) moves across the boundaries between two cells, the SS performs a handover (HO) that incurs the HO processing delay, which potentially impairs the latency quality of the Internet. Therefore, due to the HO and many other special characteristics of WiMAX, it is quite important and desirable to evaluate the performance of various Internet application services via WiMAX, like VoIP, online game, etc.

For years, there are many studies not only to design games more resilient to network conditions, but also to improve the networking environments. A great amount of work has been carried out to evaluate online game performance via various network access systems, e.g, WLAN [4] and GPRS [5]. In this paper, we carry out measurement and evaluation of the performance of World of Warcraft (WoW) over the mobile WiMAX networks, including the analysis of high-layer packet dynamics and link layer characteristics. How to enhance WiMAX networks to better support online gaming service is also discussed. To our best knowledge, this is the first work to comprehensively measure and evaluate the performance of online games over the mobile WiMAX network.

We highlight the main contributions from our study: 1) We measure and evaluate the performance of online gaming via WiMAX considering two aspects: a) the characteristics of online gaming traffic at higher layer, such as delay, bandwidth consumption, and packet loss rate; b) link level dynamics specific to WiMAX networks, such as signal quality, handover, multi-user service and bandwidth request piggyback. 2) We analyze the disadvantages and advantages of playing online games via WiMAX, and offer suggestions about how to improve WiMAX system and to enhance the performance of WiMAX online games. 3) We make the traces publicly available in the Internet for further research on WiMAX online gaming.

The paper is organized as follows: In Section II we discuss related work and our motivation. In Section III we describe the measurement methods. Section IV and Section V show the measurement and analysis results. And we conclude our paper in Section VI.

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II. Related Work & Motivation

A lot of previous work has been carried out for evaluating WiMAX system, such as general measurement work in [6], and VoIP measurement in [7]. Some work specifically focuses on delay [8] and bandwidth request piggyback mechanism [9]. As the online game is a representative real-time application mostly utilizing TCP protocol, investigating the quality of real-time TCP performance over WiMAX is surely important. However, no previous work has yet investigated the capability of WiMAX networks to guarantee the quality of service for real-time applications like online games.

Turning to scope of online gaming research, substantial work has been done within the last ten years. For instance, [10] analyzes and discusses detailed issues of the Massive Multi-player Online Role-Play Game (MMORPG). The traffic of Lineage 2 is analyzed in [11], and [12] has analyzed and modeled the traffic of the World of Warcraft (WoW). The work in [13] discusses game playing time impacted by network Quality of Service (QoS) including the latency, jitter and packet loss, since the quality of online games essentially relies on the quality of network access. Also many researchers focus on how Internet access influences gaming experience, e.g., the WLAN has been measured in [4], and the GPRS has been tested in [5]. Consequently we are motivated to comprehensively investigate and adequately utilize WiMAX for online gaming. This paper extends our two-page abstracted poster in [14].

III. Measurement Methodology

A. H/W and S/W Setup

We choose the most famous MMORPG, World of Warcraft (WoW), which achieves more than 10 million players till now, as a representative of online game for our measurement. The MMORPG typically provides unique experiences for players to interact with others in a virtual society or world. As it requires less strict timely delivery of data than first-person shooting games and real-time strategy games, it is easier for people to play MMORPG in wireless/mobile environments, which is more prone to delay and jitter.

Our measurement device is an Apple Macbook Pro with Intel Core 2 Duo CPU T8300, 2G RAM, and Nvidia 8800GT graphic card. This specification is fast enough to run WoW with the speed of at least 50 frames per second, so that the performance of playing WoW will not be impacted by the hardware. We equip the Macbook with a USB dongle based WiMAX network interface card (NIC). Also we use the XRO7000 Diagnostic Monitor from the XRONet [15] in order to capture low layer behaviors of WiMAX. For higher-layer measurement, we use tcpdump-based Wireshark and TCPTrace.

B. Scenarios and Environment

In order to comprehensively evaluate WoW performance via WiMAX, we choose three routes: 1) **subway**: We take subway line 2, one of the most popular metro lines in Seoul. In the subway line 2, one WiMAX BS is deployed at almost every subway station, and one or more repeaters are installed along the subway tunnel between adjacent stations to enhance the radio signal between SSs and BSs. Hence, whenever, he subway trains moves across between two stations, there should be HO(s). 2) **bus**: We take bus 501 from Seoul National University (SNU) to Seoul Railway Station; this route passes by a few university campuses, several apartment complexes, one tunnel, the Han River bridge, shopping malls, etc. While the bus goes through the Seoul metropolitan area, the SS inside the bus performs HOs among BSs. 3) **Campus**: We measure the WoW performance inside the SNU campus, where only one BS and a few repeaters cover the entire area. Here we carry out two sub-tests: a) stationary: we fix the location of the laptop near the window in a dormitory; b) mobile: we move around the campus in a shuttle bus. Overall, we believe these three routes can characterize most typical network statistics in the mobile WiMAX networks.

Even though a user participates in the same game, the game traffic patterns (i.e. the way in which packets are exchanged between the SS and the game server via the BS) can vary widely depending on what scenario or which place in the virtual world he/she is playing the game in currently. To reflect the effect of different traffic patterns [10], we investigate three game scenarios: 1) **downtown**: Numerous players in WoW (and also in other MMORPGs) gather together at popular areas, e.g. a main city, for the purposes of trading, chatting, refreshing and so on. To this end, we make our avatar move in the Dalaran city in WoW. This scenario generates low rate of uplink packets but high rate of downlink packets due to high density of players. 2) **hunting**: in WoW, a player should always kill monsters to raise his/her level, to obtain money and equipments. We control the avatar to hunt monsters one by one continuously in a desolated map, Silithus. This scenario indicates the interaction between the player and the environment, so called Player versus Environment (PVE). Here both uplink and downlink traffic will be low. 3) **battlefield**: A player can experience an exciting fight when dueling with other players. In WoW, arenas offer fighting opportunities for groups, and some even bigger battlefields support dozens or even hundreds of players to enjoy battling. We attempt to join the battlefields of Arathi Basin (15 people) and Wintergrasp (hundreds of people). This situation indicating the active interaction among people, called Player versus Player (PVP), which exhibits both high uplink and downlink traffic.

Each measurement result is obtained from tests for more than 5 times, except the battlefield case by bus, which is tested 3 times due to the issue of laptop battery depletion. Overall we capture WoW traffic with about 0.76 million packets, and because of secure and confidential issues, a part of the traces are shared in the Internet [16] [17].

IV. Higher-Layer Analysis

In this section we discuss the delay with jitter, bandwidth consumption and packet loss rate for the three gaming scenarios via the different routes in mobile WiMAX networks.

A. Delay and Jitter

It is observed in [13] that average session time of users decreases significantly if the delays of interaction in games are high, and players are more sensitive to large delay variation than to high delay. So we focus on the RTT and the jitter as the main metrics to evaluate delays in the experiments. (Many references consider RTT as the major metric [10] [11] [14].)

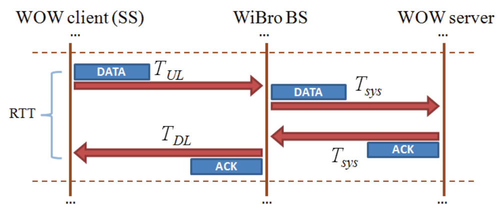


Fig. 1. Round Trip Time in WoW via WiMAX

1) Round Trip Time (RTT): We firstly model the RTT as follows: WoW leverages TCP as the transmission protocol, so the RTT is actually the duration of a round trip exchange of TCP data and its acknowledgement (ACK), as illustrated in Fig. 1. Initially, a TCP data packet containing the updated information of the avatar's action is sent to the WoW server, taking time of $T_{UL} + T_{Sys}$, where T_{UL} is the uplink delay in the WiMAX access network from the client (or SS) to the serving BS, and T_{Sys} is the delay between the serving BS and the WoW server through the WiMAX backhaul and Internet backbone. The WoW server instantly calculates the consequences of the avatar's action and returns the result to the client, with an updated TCP ACK sequence ID, taking time of $T_{Sys} + T_{DL}$, where T_{DL} is the downlink delay from the WiMAX serving BS to the client and we assume the transfer delay between the BS and the WoW server is symmetric. Therefore, we model the RTT by calculation:

$$RTT_{model} = T_{UL} + T_{sys} + T_{sys} + T_{DL}$$

From the previous measurement on the same WiMAX networks [8], we obtain that on average, T_{UL} is 80.1 ms and T_{DL} is 25.5 ms, due to the asymmetric design of uplink and downlink access capacity and bandwidth allocation mechanisms; we trace the packet route and measure that T_{sys} is normally around 10 ms, so $RTT_{model} = 125.6$ ms.

On the other hand, we measure the real RTT of every uplink packet, RTT_{real}, from all captured traces of the three scenarios in the three routes by TCPTrace, and the statistics are summarized in Table. I. The overall average RTT_{real} is 121.87 ms, close to our estimation of RTT_{model} (125.6 ms). We also record the practical latency displayed in the WoW client, called WoW latency, which is refreshed every 30 second. The average WoW latency is 289.69 ms as shown in Table. I. The relationship between RTT and WoW latency is under study for future work.

We make the cumulative distribution functions (CDFs) of all RTT values as shown in Fig. 2. In the downtown scenario in Fig. 2(a), the campus case has the best performance since there is no HO and signal quality is relatively good. However in bus route, high RTT values take much more portion, because there are frequent HOs, which incur many transmission errors and thus retransmissions inducing high delays. Even in absence of HOs, the WiMAX signal quality varies substantially due to the shadowing in outdoor environments because of buildings, hills and so on. In the hunting situation in Fig. 2(b), as the traffic of both uplink and downlink is low, we can see the three cases exhibit nearly the similar RTT values. In the battlefield in Fig. 2(c), the overall RTT is relatively low, because the uplink has high amount of traffic where the WiMAX uplink piggyback mechanism (to be detailed in Section V-D) improves the uplink delay. Note that in subway route of three scenarios, although HOs happens frequently, the RTT is actually small due to good signal quality (to be detailed in Section V-A).

Our RTT estimation considers no mobility but some of our tests are in mobile environment, so the RTT_{real} should be higher than RTT_{model}. The reason why the RTT_{model} is actually higher can be conjectured as follows: the request piggyback mechanism can significantly improve the RTT by reducing the T_{UL}, which is not considered in our estimation, so in battlefield scenario the RTT is is reduced to only 117.73 ms; also the T_{UL} and T_{DL} values are from former tests last year [8] when the WiMAX Wave 1 was deployed, but we tested when the KT is implementing WiMAX Wave 2, which is an improved version of Wave 2 with smaller network delay.

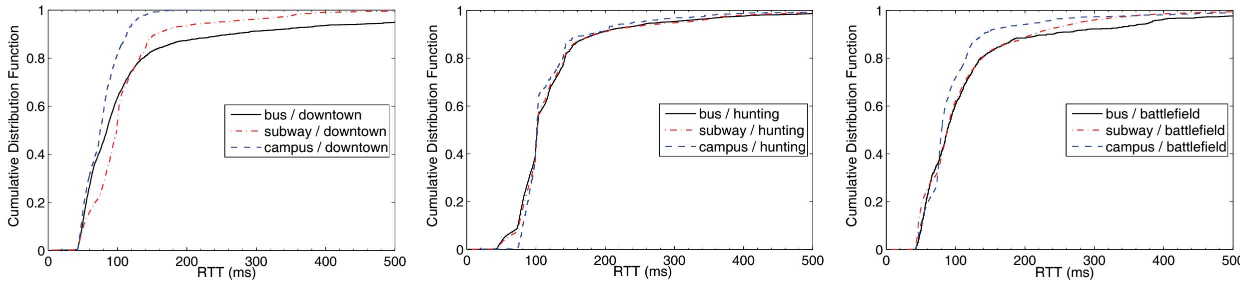
TABLE I
ROUND TRIP TIME AND WOW LATENCY (MS)

	Downtown	Hunting	Battlefield	AVG	WoW Latency
Bus	176.26	128.96	127.18	148.13	319.35
Subway	114.48	130.92	106.21	119.73	291.22
Campus	77.39	122.21	112.55	103.04	279.74
AVG	124.26	129.62	117.73	121.87	289.69

2) Jitter (RTT Variation) and HighDelay: Players tend to be more sensitive to large delay variation than to high delay [13], so we compute the standard deviation of RTT as shown in Table II. Clearly, the client (or SS) in the bus route suffers high delay variation due to the dynamically changing signal quality and HOs, while the jitter of subway is smaller. In a stationary environment, there hardly exists sudden changes of the delay due to the stable signal. In order to obtain how often and how long the SS suffers unacceptable delay variation, we compute the average RTT at the interval of 1 second, and then we identify the RTT peak over 200 ms as the start of the *high delay*, which is quite unacceptable for players; as soon as the RTT falls below 200 ms, we

TABLE II
RTT VARIATION, AND HIGH DELAY (MS)

	Bus	Campus/stationary	Campus/mobile	Subway
RTT variation	35.32	9.30	14.59	21.23
WOW Latency	87.24	20.51	30.74	49.42
Portion of high delays	4.88%	/	0.81%	2.71%
AVG high-delay duration	3.16 s	/	1.1 s	2.06 s



(a) RTT - Downtown (b) RTT - Hunting (c) RTT - Battlefield

Fig. 2. CDF of Round Trip Time

conclude that the high delay duration ends. We record the durations of those high delays, and then calculate the portion of the delays to entire test period, as shown in Table II. The portion of high delays in the bus case is almost 5%, which may hinder player's experience. Meanwhile, the high delay happens rarely in campus and subway routes. Most of high delay durations fall between 1 and 3 seconds, but the actual delay experienced by a user may be even longer considering the TCP congestion/error control mechanism and MMORPG real-time interactivity requirements.

B. Bandwidth Consumption

From the WiMAX standards [1] [2], by adaptive modulation and coding, the maximum aggregate bandwidth in each BS of WiMAX Wave 1 is 18.5 Mbps for downlink and 5 Mbps for uplink, and that of WiMAX Wave 2 is 37.5 Mbps for downlink and 10 Mbps for uplink in each BS. Also it is measured and reported [6] that the practical maximum aggregate goodput (UDP traffic) of a single WiMAX BS is 10.56 Mbps for downlink and 3.09Mbps for uplink. Also [6] tested the TCP throughput for a single SS as 2.45 Mbps for downlink, and 1.77 Mbps for uplink. To summarize, the MMORPG is not bandwidth-consuming application as we show the measurement results of the bandwidth consumption in the three gaming scenarios in Table. III. Because of the global cooldown system [12] of WoW, a player's avatar can perform only one action every 1 to 1.5 seconds. This strategy improves the excitement of gaming experience, and also maintains the uplink traffic to a relatively low level. As for downlink, when the avatar is in downtown or in battlefield, the traffic peak rate can be as high as a few hundreds of Kbps, but the average traffic rate is not high. On average, WoW only consumes 3 to 4 Kbps for uplink and no more than 40 Kbps for downlink. In peak rate cases, the maximum observed traffic of uplink is 32.11 Kbps, and that of downlink is 344.31 Kbps. In this regard, we conclude that WiMAX can support online gaming well as long as the BS is not saturated. Saturated case is discussed in Section V-C.

C. Packet Loss Rate

Packet loss rate can affect the game service quality substantially [13]. Thus we measure the ratio of lost packets at the TCP layer in various cases as shown in Table. IV. Recall

TABLE III
BANDWIDTH CONSUMPTION (KBIT PER SECOND)

	UL	MAX-UL	DL	MAX-DL
Downtown	3.42	64.23	13.12	344.31
Hunting	2.18	7.74	8.93	71.23
Battlefield	3.74	42.50	32.11	229.29

that in the campus case, we also carry out the stationary and mobile tests. We found that the uplink has low packet loss ratio on average, but that of downlink often exceeds 2%, which is not tolerable for the real-time online game service. Also it is shown that the packet loss rate is much higher in the mobile case than stationary case, where the quality of signal is fluctuating over time and HOs induce interruptions of transmissions, then packet transmission will be fragile.

TABLE IV
PACKET LOSS RATE

	Bus	Campus/stationary	Campus/mobile	Subway
Uplink	0.31%	0.19%	0.42%	0.40%
Downlink	2.85%	1.31%	2.42%	2.04%

V. ANALYSIS OF LOW-LAYER IMPACT

In this section, we investigate how online game performance is impacted by the low layer characteristics of WiMAX based on the Carrier to Interference and Noise Ratio (CINR), HO, Best Effort (BE) service and piggyback.

A. CINR

The CINR is the most important physical layer factor in WiMAX. Low CINR values will trigger the SS to change the PHY layer modulation and coding scheme to low PHY bit rate, or to handover to another BS with higher CINR. Fig. 3 shows the statistics of CINR values of the different routes. Clearly the bus situation exhibits the poorest CINR condition because the bus always move around large buildings, hills and even tunnels, also the outdoor environment with many obstacles impacts the channel quality significantly due to the shadowing. In the subway case, we find a BS is deployed almost at every subway station, and even in tunnels there are repeaters. So the CINR is actually high, and a SS always performs HOs to the next BS in the next station before the signal condition becomes

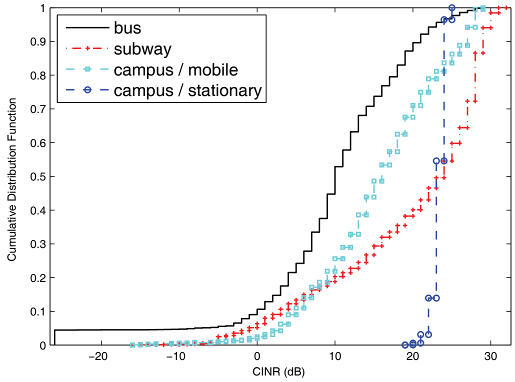
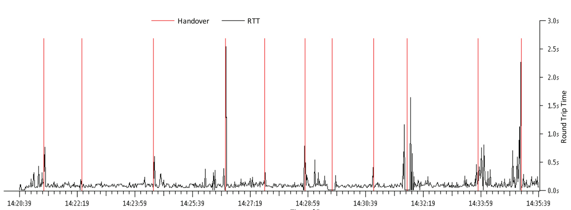


Fig. 3. CINR Values of Different Routes

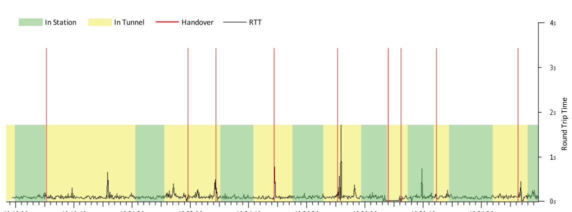
bad. Inside the SNU campus, the CINR varies since the topography of trees and buildings always changes. Obviously the radio signal keeps almost constant when our device is stationary under a good channel condition.

B. Handover Impact

A HO in WiMAX comprises several steps inducing a non-negligible delay, even though some optimization is defined in the standard, so it may impact the real-time online gaming services. We focus on bus and subway cases to observe how HOs impact the game performance in terms of RTT. Fig. 4 shows RTT plots with the time of the day during the measurement, and the HO occurrences are indicated by red vertical lines, which are obtained by observing the MAC frame *MOB_MSHO_REQ_START* from the XRO7000 Diagnostic Monitor trace. The correlations between the RTT and HO in the bus route and the subway route are shown in Fig. 4(a) and Fig. 4(b) respectively. In the latter, a green block shows a period when the train is in a station and a yellow block shows that when the train is moving in a tunnel between two stations. Investigating from the fluctuations of RTTs, due to



(a) Handovers in Bus Case



(b) Handovers in Subway Case

Fig. 4. Impact of HOs on RTT

the Ho processing time between two BSs, the RTT may often rise around 500 ms suddenly at HOs, or even go above 1 or 2 seconds. In the subway situation, one or two HOs as well as RTT fluctuations always happen when the train is in the tunnel, since the SS performs a HO between the serving BS and the next BS at the coming station. We found that not every fluctuation exactly corresponds to a HO, because the changes of tunnel shapes, such as curvature, may influence the signal quality. Also HOs do not always induce sudden rises of RTTs, because a HO in the subway case often takes place when the train moves into the next station, not due to poor signal strength. Therefore a HO happens with small delay under good signal condition. In contrast bus situation, WiMAX BSs are not deployed as densely as subways, so HOs happen mostly when the SS has poor signal quality with the current BS compared with other BSs; thus, a HO induces longer delay.

C. Best-Effort (BE) Service for Multi-user

The WiMAX standards [1] [2] [3] specify that, for the traffic of real-time application with variable packet size on a periodic basis, the extend real-time polling service (ertPS) at the BS should be implemented. However, currently only the Best Effort (BE) service is deployed in the WiBro, which means all packets are treated equally in a best effort manner by the BS. Therefore, when the aggregated traffic at a BS tends to be saturated, the flow of an online game application will be treated equally as other flows such as FTP or P2P, thus ignoring the real-time requirements of online game services. Accordingly the packet transmissions of the WoW flow may be delayed.

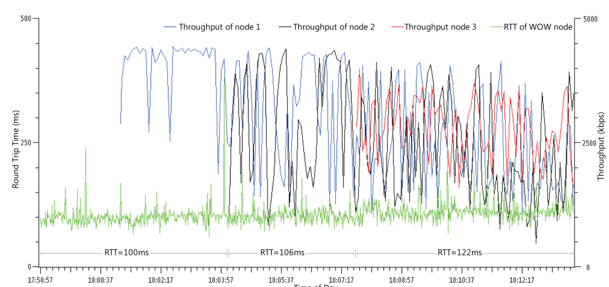


Fig. 5. Multi-user Measurement

We carry out measurement with four WiMAX accessed laptops and Fig. 5 plots the throughputs and RTTs of SSs in the experiment. When one SS keeps playing WoW, we start three FTP connections at the other three laptops respectively. When we turn on the first and second FTP laptops in order, they both achieve around 3.9 Mbps throughput, and the RTT of the WoW traffic varies little around 106 ms. When we turn on the third FTP laptop, the throughputs of the first two FTP connections are degraded to around 3.1 Mbps, and the throughput of the third FTP connection achieves around 3.0 Mbps, while the RTT of the WoW flow is increased to around 122 ms. This test demonstrates the tendency that if there are more and more bandwidth-consuming connections, the RTT of a WoW flow will be increased drastically. So the BE service may not service online gaming flow effectively in the presence of multiple users; the ertPS approach should be taken.

D. Packet Interval Effect on RTT

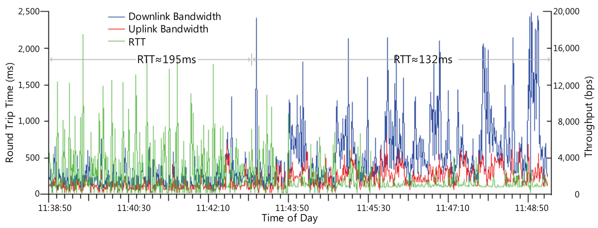


Fig. 6. Impact of Piggyback on RTT

We also carry out interesting measurement on how the uplink packet rate impacts RTT. Initially, the avatar stands alone and takes no actions, and after a while, it performs many actions to kill monsters in the same environment. As shown in Fig. 6, the red and blue plots of uplink and downlink traffic rates respectively are low when the avatar is idle at the beginning, while the green plot of RTT fluctuates notably around 195 ms. When the avatar takes actions continuously thus many packets are frequently generated, the RTTs drop to low and stable values around 132 ms. This counter-intuitive phenomenon that higher traffic rate of uplink shortens the RTT of each packet, is due to the piggyback mechanism in WiMAX uplink transmissions [8] [9]. Normally every uplink transmission should be requested to the BS, and then the BS allocates slots in uplink bandwidth capacity, which may take considerable time before actual transmission. But if there are continuous uplink packets being transmitted in the buffer, such a bandwidth request can be efficiently piggybacked into the previous uplink packets. Therefore higher uplink rate will increase the possibility to send uplink packets without bandwidth request, thus shorten the RTT. We will enhance the analysis on this issue in our future work.

VI. Conclusions and Future Work

In this paper, we measured and analyzed the performance of World of Warcraft (WoW), as a representative of online games, over the mobile WiMAX networks. We focus both application level packet statistics such as delay and bandwidth, and low level (or WiMAX PHY/MAC layer) characteristics such as CINR, handover and piggyback. To measure the WoW performance in a comprehensive manner, we consider different test routes of bus, subway and campus (stationary and mobile), with various gaming scenarios of downtown, hunting and battlefield.

Generally the online gaming via WiMAX has acceptable performance. Players can enjoy online gaming in most of the time. But sometimes high delay may happen, even more frequently when a SS is in the bus, while the performance is better in subway case. As we analyzed, there are many issues constraining the performance. Firstly the handovers have a critical influence so the WiMAX service providers should always optimize the handover processing time. Also the game should be aware of HOs, thus be able to adapt to the sudden interruption to smoothen the latency. Although not very high load of online gaming traffic can be handled by WiMAX BS, but the current best effort service in WiMAX networks may not be suitable to support real-time online gaming well due to competition with other bursty flows. In order to make an online gaming flow be allocated stable bandwidth, the extended real-time polling service (ertPS) should be implemented at the BS. Another method to further reduce uplink transmission delay is to leverage the piggyback mechanism: the uplink packet rate should be raised higher than a certain threshold, which should be further studied, to fasten the uplink transmission. Our main future work on the online gaming via mobile WiMAX will focus to excavate more useful findings to improve the performance, and to design appropriate networking transmission schemes. We believe that the online gaming via the WiMAX handsets, with the support of metropolitan Internet connectivity, shows the potentially promising opportunity of the huge marketing of next generation mobile gaming.

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