Unveiling the BitTorrent Performance in Mobile WiMAX Networks

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Abstract. As mobile Internet environments are becoming widespread, how to revamp peer-to-peer (P2P) operations for mobile hosts is gaining more attention. In this paper, we carry out empirical measurement of BitTorrent users in a commercial WiMAX network. We investigate how handovers in WiMAX networks impact the BitTorrent performance, how BitTorrent peers perform from the aspects of connectivity, stability and capability, and how the BitTorrent protocol behaves depending on user mobility. We observe that the drawbacks of BitTorrent for mobile users are characterized by poor connectivity among peers, short download session times, small download throughput, negligible upload contributions, and high signaling overhead.

Keywords: Mobile WiMAX, BitTorrent, Measurement

1 Introduction

Over the past decade, peer-to-peer (P2P) file sharing applications have generated dominant Internet traffic. Also, more and more users are accessing the Internet in mobile environments due to the advances of portable devices and the increase of wireless link capacity. These trends will lead to the increasing usage of P2P applications in mobile networks; mobile P2P traffic is expected to be about 277 petabytes per month, 10% of the world's mobile Internet traffic by 2014 [1].

WiMAX and 3GPP LTE networks are gaining momentum as candidates for the next generation mobile networks, aiming to provide broadband link bandwidth and mobility support. However, mobile users in these networks will experience link quality fluctuations and handovers. Therefore, mobile P2P applications should address the following drawbacks: substantial link dynamics due to fading, disruptions during handovers, and the imbalance of link conditions between mobile and wireline users.

Current P2P applications are however designed by assuming wireline hosts that avail themselves of high and stable link bandwidth. Therefore measurement and analysis of how the current P2P protocols behave in mobile environments can be a foundation for new mobile P2P protocol designs, which motivates our measurement study of BitTorrent in mobile WiMAX networks.

Even though numerous service-oriented measurement studies, e.g., [2][3][4][5], have been carried out in real WiMAX, no work has focused on measurement of the P2P performance in WiMAX. There have been a few studies on how to design proper protocols for wireless/mobile P2P services without measurements. Huang *et al.* [6] proposed a new hierarchical P2P scheme that seeks to cluster nearby peers considering their network prefixes. They carry out simulations with WiFi-connected peers, without considering mobility. Wu *et al.* [7] designed a network architecture for a mobile P2P network consisting of ships in maritime environments. They leverage flooding to find a file among ships, which is not efficient in mobile P2P scenarios; also, they rely only on simulations. Hsieh and Sivakumar [8] discussed how cellular networks can support P2P communications; however, there was no empirical study of mobile P2P performance.

Recently Kim *et al.* [9] carried out preliminary P2P measurements in a commercial WiMAX network in Korea, dealing with traffic metrics, control overhead, and peers' performance. This paper is further extended based on the same log explicitly targeting the handover impact, peers' connectivity and stability, and control signaling delay. To the best of our knowledge, we are the first to carry out comprehensive empirical study of the BitTorrent performance in the mobile WiMAX networks, with following contributions:

- We empirically measure BitTorrent performance of mobile users in commercial WiMAX networks and the log data is shared in public[1].
- We measure how handovers (HOs) degrade the performance of BitTorrent. We observe that, on average, a HO reduces the throughput, number of connected peers, and number of actively transmitting peers by 32.4%, 1.4%, 14.9% in the bus case, and by 14.7%, 3.5%, 0.5% in the subway case, respectively.
- We investigate how BitTorrent behaves with user mobility in terms of connectivity among peers, download/upload duration and throughput. Frequent disconnections, short download session times, small download traffic, and negligible upload contributions characterize the BitTorrent performance in mobile environments.
- We analyze BitTorrent signaling overhead over the WiMAX network. Relatively long RTTs and link instability make the BitTorrent signaling protocol more inefficient, with longer processing time.

The rest of this paper is organized as follows. Section 2 describes measurement settings and test routes. We measure how handovers impact the BitTorrent performance in Section 3. Sections 4 and 5 analyze the application level performance of BitTorrent users and the BitTorrent signaling efficiency, respectively. Concluding remarks are given in Section 6.

2 Experiment Description

2.1 Measurement Settings

We carried out the measurements in KT's mobile WiMAX network in Seoul, Korea, which has more than 300,000 subscribers as of March 2010. In the WiMAX

[1] http://crawdad.org/snu/bittorrent

network, one base station (BS) offers the aggregated throughput of approximately 30 to 50 Mbps, and typically covers an area with a radius of 1 to 5 km. Depending on the distance between a BS and a subscriber station (SS), the channel condition and its bit rate can vary substantially. (In this paper, we use the terms "SS" and "WiMAX host" interchangeably.) When an SS crosses the boundary between two BSs, it performs a HO, during which BitTorrent download/upload will be affected. Time-varying link conditions, inter-cell interference, and HOs adversely affect the BitTorrent performance.

We use three laptop computers, each with a WiMAX modem, for measurements. The three WiMAX modems are one KWM-U1000 and two KWM-U1800s [10]. Another desktop computer is connected to the 100 Mbps Ethernet in the campus network of Seoul National University for comparison purposes. We modify the open-source BitTorrent software, *Vuze* [11], to record logs every 0.5 second, e.g. peer list, download and upload rates. *WinDump* is used to capture the packet headers; *Wireshark* and *TCPTrace* are used to analyze the traces. We also use the XRO7000 toolkit [12] to observe the WiMAX link layer activities such as the signal strength and HO messages.

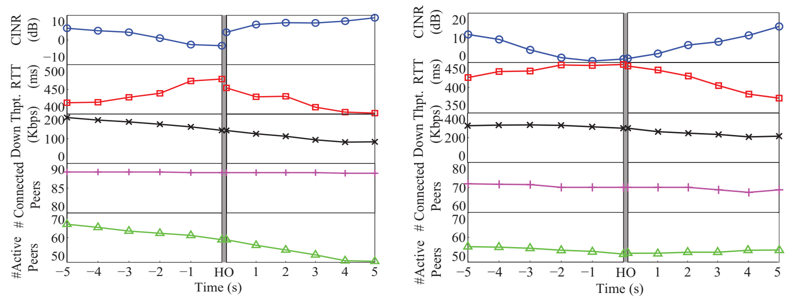
2.2 Test Routes

Based on the similar measurement studies [2][4][5][9], we consider three scenarios of WiMAX hosts: (1) **Stationary**: An SS is located stationarily inside a building in the university campus, where a single WiMAX BS and a few repeaters cover the entire campus area. The distance between the SS and the BS is about 800 meters without line-of-sight path; thus, the received signal strength is stable but not strong. (2) **Subway**: We take the subway line #4 in Seoul Metro, from Sadang station to Myeong-dong Station. The distance is about 12 km and it takes about 20 minutes; there are 10 subway stations on the route. At every subway station, a single BS is deployed, and one or more repeaters are installed between adjacent BSs to enhance the radio signal. Therefore, HOs occur whenever a subway train moves from one station to another. (3) **Bus**: We take the bus #501 from Seoul National University to Seoul Railway Station. The distance of the bus route is about 11 km and it took about 30 minutes when we carried out the measurement.

We select a popular 400 MB video file, 25 minute long sitcom; at least 300 seeds are participating in the BitTorrent network. We carry out experiments four times over four days in March, 2010; in each run, four hosts (Ethernet, stationary, subway, and bus) start downloading the same file at the same time.

3 Impacts of Handovers

WiMAX adopts a break-and-make HO approach; thus, the throughput of the WiMAX host is noticeably disrupted. We trace all HOs by observing the two IEEE 802.16e MAC frames: *MOB_MSHO_REQ* indicating the beginning of a HO, and *HO_RNG_SUCCESS* indicating the end of the HO. Then we average



(a) Bus Case (b) Subway Case

Fig. 1. How HOs impact the BitTorrent performance

Table 1. Calculation of How HOs Impact the BitTorrent Performance

	The Bus Case			The Subway Case		
Averaged Metrics	Before	After	Change	Before	After	Change
CINR (dB)	2.3	5.4	3.1 (N/A)	5.1	7.5	2.4 (N/A)
RTT (ms)	446.2	413.4	-32.8 (7.3%)	440.7	419.9	-20.8 (4.7%)
TCP throughput (Kbps)	174.5	117.8	-56.6 (32.4%)	287.1	244.8	-42.3 (14.7%)
#Connected peers	87.6	86.6	-1 (1.4%)	71.2	68.7	-2.5 (3.5%)
#Active peers	63.8	54.3	-9.5 (14.9%)	54.3	54.0	-0.3 (0.5%)

relevant metrics at one second intervals. The changes of metrics over time (within 5 seconds before and after the HO) are shown in Fig. 1, where the vertical line in the middle indicates the HO occurrences. We observe that in the bus case, before the HOs, the carrier-to-interference ratio (CINR) always drops below 0; hence, 0 dB may be the threshold to trigger a HO in the KT's WiMAX network. During a HO, packet transmissions are disrupted; thus, the retransmission timeout may expire, which in turn reduces the TCP congestion window. Notice that the download throughput in the bus case is nearly halved after the HO, and still keeps on decreasing due to the slow recovery of TCP congestion control. What is worse, the number of the actively transmitting peers is notably decreasing before and after HOs in the bus case. On the other hand, in the subway case the effect of HOs is less severe; the RTT around a HO increases and hence the download throughput decreases.

We calculate the average value of each metric before and after HOs, and show the changes in Table 1. On average, a HO reduces the RTT, throughput, number of connected peers, and number of active peers by 7.3%, 32.4%, 1.4%, 14.90% in the bus case, and by 4.7%, 14.7%, 3.5%, 0.5% in the subway case, respectively. We observe that TCP transmissions are impacted by HOs the most significantly.

4 BitTorrent Dynamics for Mobility in WiMAX

To evaluate the behaviors of BitTorrent protocols with other peers from a WiMAX host's view, we define the following terms, which are also illustrated in Fig. 2:

- **Connection Session (CS)**: it starts from the establishment of a connection with a particular peer, and ends when the peer is disconnected. If the host is disconnected from, but reconnects to the same peer again after 1 second, we count them as two separate CSs. This term indicates the peers connectivity.
- **Download/Upload Session (DS/US)**: it means a download/upload duration during a single CS. We define that a DS/US ends if there is no packet transmissions for longer than 1 second. These terms show the download/upload stability.
- **Download/Upload Traffic (DT/UT)**: it refers to the downloaded/uploaded traffic load in bytes during a single DS/US. These terms indicate the download/upload capability.

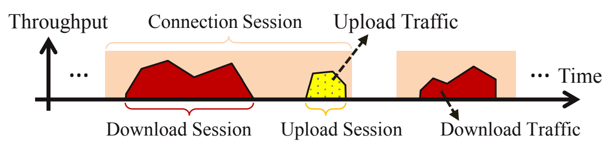


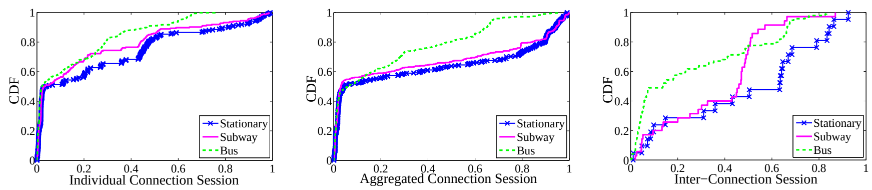
Fig. 2. An Illustration of A Peer's Connections and Downloads/Uploads

A WiMAX host may connect to (and be disconnected from) the same peer multiple times. Thus, we define a peer's **aggregated CS**, **aggregated DS/US** and **aggregated DT/UT** by summing CSs, DSs/USs and DTs/UTs with the same peer. Note that all CSs and DSs/USs are originally in unit of seconds, but normalized to the total download time of each case, respectively for comparison purposes. The total download times are 243.28s, 1208.05s , 1326.44s, and 1964.86s in the Ethernet, stationary, subway, and bus cases, respectively.

We observe that disconnections from other peers are caused by: (a) bad link conditions due to fading and mobility (passive disconnection), and (b) BitTorrent operations due to lack of incentives (active disconnection). We analyze CSs and DSs/USs of the WiMAX hosts caused by passive disconnections in the following sections to observe how WiMAX network impacts the BitTorrent performance.

4.1 Peer Connectivity

A TCP connection of a WiMAX host with a peer will be kept until it is actively closed by the peer's BitTorrent operation, or is passively disconnected due to bad link conditions. Active and passive disconnections can be determined by checking whether there is a TCP *FIN* flag at the end of a CS. We observe that the ratio



(a) CS distribution (b) Aggregated CS distribution (c) Inter-CS distribution

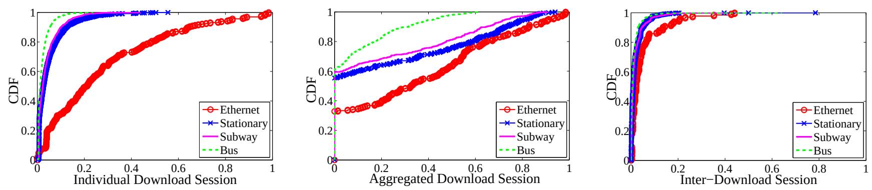
Fig. 3. Peer Connectivity

of the CSs ended by passive disconnections to all the CSs is 0%, 87.2% , 88.7% and 92.1% in the Ethernet, stationary, subway, and bus cases, respectively.

We show the cumulative distribution functions (CDFs) of CSs and aggregated CSs in Figs. 3(a) and 3(b), respectively. We observe that more than 50% of the CSs are extremely short, less than 2% of the total download time. In the bus scenario, around 80% of the aggregated CSs are shorter than half of the total download time, but in the subway and stationary scenarios, about 40% of the aggregated CSs are longer than half of the total download time. We also plot the CDF of idle durations between the adjacent CSs to the same peer, dubbed **inter-CS** times, in Fig. 3(c). In the bus case, half of the inter-CSs are shorter than 10% of the total download time, which indicates frequent disconnections and reconnections to the same peers. Frequent disconnections indicate poor connectivity to peers; the bus scenario exhibits the poorest connectivity since its wireless link is highly fluctuating while the bus moves in outdoor environments. Table 2 shows the statistical averages of CSs, aggregated CSs and inter-CSs of each scenario, and we compute that, on average, WiMAX hosts performance worse than Ethernet one, and the bus host performance the worst.

Table 2. Averages of the metrics are shown where ind., agg., inter- stand for individual, aggregated, inter-session times, respectively. All session times are normalized to the total download time in each case, and the unit of the traffic is KB.

	CS			DS			DT		US		UT	
	ind.	agg.	inter-	ind.	agg.	inter-	ind.	agg.	ind.	agg.	ind.	agg.
Ethernet	N/A	N/A	N/A	0.286	0.350	0.049	1818	1972	0.026	0.232	87	791
Stationary	0.253	0.352	0.487	0.052	0.227	0.020	227	2107	0.006	0.056	55	542
Subway	0.201	0.327	0.396	0.043	0.181	0.019	192	2113	0.005	0.081	50	855
Bus	0.155	0.210	0.259	0.021	0.088	0.013	133	1281	0.003	0.031	21	205



(a) Individual DS (b) Aggregated DS (c) Inter-DS

Fig. 4. Download Stability

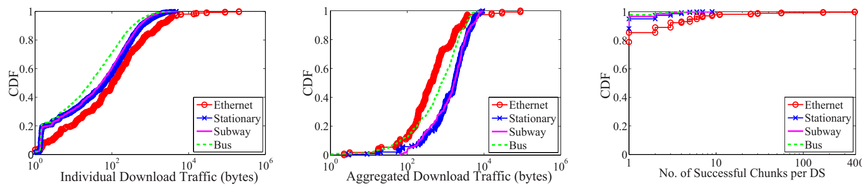
4.2 Download Stability

Download sessions (DSs) may be interrupted or terminated by multiple reasons: (a) bad link conditions incur large RTTs and frequent packet losses, so that TCP connections can be disrupted, (b) a chunk delivery (with chunk size of 512 KB for a 400 MB file [11] [13]) is finished successfully, (c) the host is so slow that it may be choked, (d) by the end of file download time, transmissions are withdrawn intentionally by the BitTorrent protocol. We exclude the latter three cases, which can be classified as active disconnections. We observe that DSs are passively disconnected (i.e. case (a)) with the ratios of 71.2%, 84.6%, 85.7%, and 91.6% in the Ethernet, stationary, subway, and bus cases, of all the DSs respectively.

The CDF of DSs due to passive disconnections is shown in Fig. 4(a), which reveals the stability of downloading the file. (Note that peers, which do not transmit data to the host, are not included in the figure.) The Ethernet host outperforms the WiMAX hosts significantly due to its high uplink capacity. Hosts in the WiMAX network suffer from short DSs; almost 90% of the DSs are shorter than 10% of the total download time. Fig. 4(b) shows the CDF of the aggregated DSs of the peers. Surprisingly the WiMAX hosts have negligible DSs from almost 60% of the peers, while the Ethernet host has marginal DSs from around 30% of the peers. The aggregated DSs (of peers) of the WiMAX hosts are much shorter than that of the Ethernet host. In particular, the WiMAX host in the bus scenario has the worst performance; 90% of its peers maintain aggregated DSs less than 40% of the total download time. We also plot the CDF of the **inter-DS** times, the inactive download periods, in Fig. 4(c), showing the inter-DS times are very short in the WiMAX cases, indicating that the download is terminated and recovered frequently. From Table 2, the average durations of individual and aggregated DSs (of peers) of the WiMAX hosts are quite shorter than those of the Ethernet hosts due to frequent interruptions and disconnections.

4.3 Download Traffic

During the DSs, the amount of the download traffic from remote peers to a host is time-varying depending on the link dynamics (and hence transmission rate



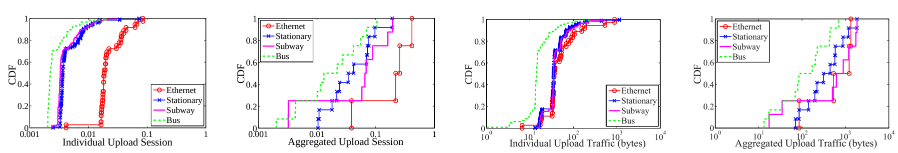
(a) Individual DT (b) Aggregated DT (c) # of Chunks per DS

Fig. 5. Download Traffic

of a channel). We measure the DT for each DS to observe how much traffic a remote peer transmits to the host. As shown in Fig. 5 (X axis is in log scale), the WiMAX host in the bus case receives the smallest DT per DS. Most of the DT to the Ethernet host are transmitted from a few peers in a short time. In contrast, the WiMAX hosts can download only a small amount of traffic from a large number of peers due to its link instability.

The effective download of a host is critical to evaluate the BitTorrent performance. We calculate the CDF of the numbers of successfully transmitted chunks during each DS. From Fig. 5(c), we observe that in the WiMAX cases, about 90% of the DSs cannot continuously download even a single chunk successfully. The average number of successful chunks per DS is 2.951, 0.218, 0.162, and 0.103 in the Ethernet, stationary, subway and bus cases, respectively. Consequently, frequent disruptions of chunk will result in retransmissions of some packets of the interrupted chunk. We suggest that reducing the chunk size may increase the efficiency of chunk delivery in mobile environments.

4.4 Upload Stability and Traffic



(a) Individual US (b) Aggregated US (c) Individual UT (d) Aggregated UT

Fig. 6. Upload Stability and Traffic

We evaluate upload stability and upload traffic similarly. CDFs of USs and UTs are shown in Fig. 6. Most of the individual USs of the WiMAX hosts exist for extremely short periods: 0.1% $\sim$ 1% of the total download time. By comparison, the Ethernet host maintains higher USs due to its stable link. Fig. 6(c) shows that the UT of each of the WiMAX cases (except the bus case) is not so different from that of the Ethernet case. It is because that there is not so much need to upload even for the Ethernet host due to the huge amount of seeds, as the content is quite popular [2]. We conclude that the small uplink capacity of the WiMAX networks along with the small percentage of leechers in the "popular" swarm relieves the WiMAX hosts of uploading the chunks.

5 Protocol Control Behaviors

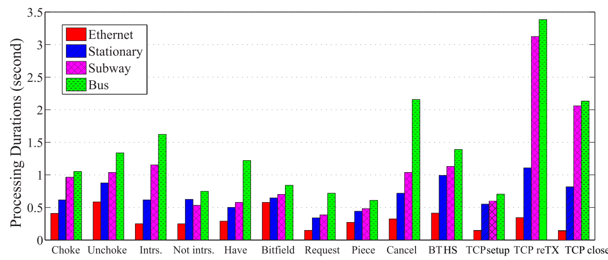


Fig. 7. The RTT of each BitTorrent control message exchange (Intrs., Not intrs., and BT HS stand for Interest, Not interest, and BitTorrent handshake, respectively.)

In this section, we evaluate the message exchange time of each BitTorrent control message, which means one RTT and the potential processing delay. We classify BitTorrent control packets [13] and then average their RTTs, as shown in Fig. 7. We observe that all control message exchanges in WiMAX cases take longer times than the Ethernet case. Thus, BitTorrent in WiMAX environments may not be able to adapt to the link dynamics timely. We also plot how long it takes to perform TCP connection setup (3-way handshake), TCP retransmission (reTX), and TCP close (2 RTTs), all of which are triggered by a host (not from a remote peer). Especially, TCP retransmissions take much longer time because they occur mostly when the link quality is not good. Consequently, large RTTs of WiMAX networks, along with TCP retransmissions, will increase the control signaling between BitTorrent peers significantly. How to optimize and revamp control signaling is crucial for BitTorrent performance in mobile environments.

6 Conclusion

We comprehensively measured and analyzed the BitTorrent performance of a host in the commercial mobile WiMAX network. Based on the empirical measurements, we reach the following conclusions: (1) the wireless links in mobile WiMAX networks are quite unstable due to the fluctuation of signal strengths and handovers. Thus connections amongst peers are often in poor conditions

[2] As we measured, about 90% of peers are seeds.

and sometimes broken depending on mobility; (2) the poor link condition degrades download performance since TCP reduces its congestion window for packet losses; (3) handovers often terminate peer connectivity and slow down the TCP transmissions, which may not be recovered efficiently; (4) due to the large delay with remote peers, the control message exchanges take noticeable time; (5) WiMAX hosts suffer from frequent disconnections, short download sessions, small download throughput, and negligible upload contributions. Overall, the current BitTorrent protocols cannot adapt to the mobile WiMAX environments well. How to adjust BitTorrent protocols in mobile environments or even to create new protocols will be our future work.

Acknowledgment

This publication is partially based on work performed in the framework of the Project COAST-ICT-248036, which is supported by the European Community. The research is also supported partly by the NAP of Korea Research Council of Fundamental Science & Technology, and the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency)(NIPA-2010-(C1090-1011-0004)). The ICT at Seoul National University provided research facilities for this study.

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