Measurement and Analysis of BitTorrent Traffic in Mobile WiMAX Networks

Seungbae Kim, Xiaofei Wang, Hyunchul Kim, Ted “Taekyoung” Kwon, Yanghee Choi
School of Computer Science and Engineering
Seoul National University, Seoul, Korea
{sbkim, dobby, hkim}@mmlab.snu.ac.kr, {tkkwon, yhchoi}@snu.ac.kr

***Abstract*—As mobile Internet environments are becoming dominant, how to revamp P2P operations for mobile hosts is gaining more and more attention. In this paper, we carry out empirical traffic measurement of BitTorrent service in various settings (static, bus and subway) in commercial WiMAX networks. To this end, we analyze the connectivity among peers, the download throughput/stability, and the signaling overhead of mobile WiMAX hosts in comparison to a wired (Ethernet) host. We find out the drawbacks of BitTorrent operations in mobile Internet are characterized by lower connection ratio, unstable connections amongst peers, and higher control message overhead.**

I. 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 explosive growth of mobile devices and the increase of wireless link bandwidth. These two trends lead to more usage of P2P applications in mobile networks; according to [1], mobile P2P traffic will grow and reach 277 petabytes per month by 2014. (around 10% of the world’s mobile Internet traffic) Mobility will affect the P2P applications as follows: (a) because of client’s mobility and signal fading, there is a large level of fluctuation in wireless link conditions, (b) there is a disruption during the handover, and (c) the imbalance in terms of link condition between mobile peers and wireline peers.

Even though mobile networks such as WiMAX and 3GPP LTE aim to provide broadband link bandwidth, they still suffer from handovers and link quality fluctuations. Legacy P2P applications are however designed by assuming wireline hosts that avail themselves of high and stable link bandwidth. We believe it is vital to measure and analyze how the current P2P protocols behave in the mobile networking environments, which motivates the measurement study of mobile users of BitTorrent in commercial WiMAX networks. Even though numerous measurement studies (e.g. [2], [3], [4], [5]) have been carried out in real WiMAX networks, no work has focused on the performance of P2P applications to our knowledge. The empirical measurement and quantitative analysis in this paper will help redesign the P2P protocols and algorithms in the presence of mobile hosts.

So far a few studies have been done on how to design proper protocols and algorithms for mobile P2P services. Huang *et al.* [6] proposed a new hierarchical P2P scheme that clusters peers considering the network prefixes of the peers. In this way, a peer can download a file with shorter round trip time (RTT). They also carry out the simulation with mobile hosts with WiFi connectivity, but there is no detailed consideration of the dynamic change of wireless link conditions, let alone handovers. Wu *et al.* [7] designed a network architecture for a mobile ad hoc network consisting of ships in maritime environments. They propose a hierarchical approach to look up a file. Basically they leverage flooding to find a file among ships, which is not useful in mobile P2P scenarios under consideration in this paper. Also, they rely only on simulation experiments as well. In [8], the modeling of P2P performance in 3G cellular is carried out by assuming there is a backbone network consisting of super peers, each of which manages its subordinate mobile hosts. However only mobile hosts are peers in the P2P scheme; there is no consideration of unfairness between mobile hosts and wireline hosts. To the best of our knowledge, this is the first empirical study of the P2P performance of mobile hosts in WiMAX networks.

The contributions of our work are summarized as follows: (1) we observe the behaviors of the hosts by monitoring the message exchanges at (WiMAX) link layer, network layer and application layer amongst BitTorrent peers, and all the captured traces and logs are shared in the Internet[1], (2) we measure the various performance metrics of BitTorrent peers in diverse user scenarios (static, subway, bus) in commercial mobile WiMAX networks, and (3) we analyze the inefficiency of P2P application protocols in case of mobile hosts in mobile WiMAX networks. Overall, a host in mobile WiMAX suffers from poor connectivity and some of the important findings are as follows. More than half of its peer connections suffer from extremely short duration, and hence the host receives no data from half of its peers. Over 90% of download durations from its peers are shorter than 10% of the entire file downloading time. The ratio of the number of BitTorrent control packets to the total number of packets is notably higher than that of an Ethernet host. Especially, a WiMAX host generates 42% more “request” and 52% more “have” control packets.

II. Methodology

We carried out the measurements in KT (Korea Telecom)’s mobile WiMAX network in Seoul, Korea. In KT’s WiMAX network, a base station (BS) offers the aggregated data

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

throughput of 30 to 50 Mbps maximum and typically covers a radius of 1 to 5 km.[2] The network supports the mobility of a subscriber station (SS) up to 120 km/h. Depending on the distance between the BS and the SS, the link condition can vary substantially. Overall, the changing link conditions and inter-cell interference make the P2P performance of a WiMAX host very unstable. Furthermore, when a subscriber station (SS) crosses the boundary between BSs, the SS performs a handover. The performance of P2P file download (and upload as well) is affected by handovers since they incur disruptions. In this paper, we use an SS and a WiMAX host interchangeably.

A. Hardware and Software Environment

We carry out the experiments by three laptops (Intel Core 2 Duo CPU and 2GB RAM), and three USB dongles embedded with mobile WiMAX modem (KWM-U1000 [9] and its upgraded version KWM-U1800). Another desktop computer (AMD Triple-Core CPU and 2GB RAM) is used to measure the performance of an Ethernet host in campus network. To measure the behaviors of peers of P2P applications, we modify the open-source BitTorrent client, *Vuze* [10], to monitor its operations. We select only popular video contents (25 min episodes of a popular sitcom), which have at least 300 seeds; their file sizes range around 300∼400 MB. We capture packet headers by *WinDump*, and analyze the traces by *Wireshark* and *TCPTrace* to monitor the P2P operations and measure the throughput, RTT and so on. The XRO7000 toolkit [11] is used to observe the WiMAX link layer activities such as the handover controlling messages.

B. Test Routes

We consider three mobility scenarios of WiMAX hosts: (1) **static**: An SS is located inside university campus network, where a single BS and a few repeaters cover the entire campus area. The location of the SS is inside a building, which is about 800 meters away from the BS. So there is no line-of-sight path; thus, the received signal strength is stable but not strong. (2) **subway**: We take subway line 4 in Seoul Metro, from Sadang station to Myeong-dong Station. Distance between two stations is about 12km and it takes about 20 minutes by subway train. There are total 10 subway stations on the route including the above two stations. Note that there is Han river (about 2 km wide) in-between. At every subway station, a single BS is deployed, and one or more repeaters are installed in a tunnel between adjacent BSs to enhance the radio signal. Therefore, handovers occur whenever a subway train moves from one station to another. (3) **bus**: We take bus 501 from Seoul National University to Seoul Railway Station. The distance of the bus route is about 11km and it takes about 30 minutes. (We avoid the rush hour.) As Seoul is a city with high population density (16,700 people per km^2), there are always many buildings and stores along the route. For instance, the topography of the route includes a few school campuses, one tunnel (about 800m), the Han River bridge, several high-rise apartment complexes. KWM-1800 modem is used for bus and two KWM-1000 modems are used for the other routes.

[2]KT's WiMAX network is working in the 2.3∼2.4 GHz band, and one channel is almost 10MHz wide and OFDMA is the physical layer technology.

III. Measurement Results

Table I shows how long it takes to download a video clip of popular 25 minute sitcoms from a host of the three mobility scenarios in March, 2010. By comparison, we also measure the download time of a host connected to 100Mbps Ethernet at the campus network. Note that the unit of file size is megabytes; date and time mean when we started the downloading experiments (time is specified by hours:minutes). We carry out experiments four runs for four days; in each run, four hosts (Ethernet, static, subway, and bus) started downloading the same file at the same time. The file download time is specified by minutes:seconds.

TABLE I
File download times of a host in each scenario for four runs

Date	Time	File size	Ethernet	Static	Subway	Bus
Mar 15	19:40	300.13	4:21	16:31	19:01	17:07
Mar 16	14:50	300.13	3:19	17:53	16:04	18:05
Mar 17	19:56	300.13	3:55	17:34	18:12	20:35
Mar 18	19:41	387.99	4:03	20:08	22:06	32:45

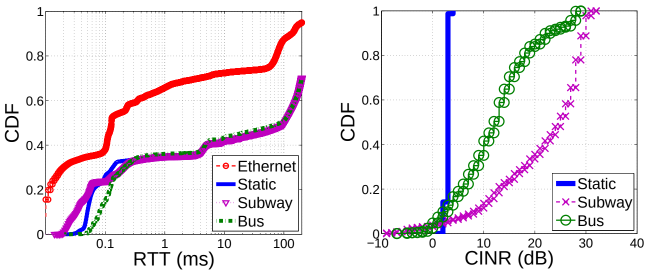
A. P2P Throughput

TABLE II
Performance of a BitTorrent host in Ethernet and WiMAX

Metric	Ethernet	Static	Subway	Bus
Avg. Download (Kbps)	1938.58	395.87	364.30	246.68
Avg. Upload (Kbps)	12.33	5.19	5.06	1.20
Avg. RTT (ms)	72.19	357.84	390.56	495.90
Avg. RTT Jitter (ms)	494.03	2152.67	2558.53	3302.19
TCP reTX (%)	3.61	8.87	8.92	8.35
Avg. CINR (dB)	-	2.87	21.28	12.35
CINR stdddv (dB)	-	0.38	9.05	7.43

We measure the various performance metrics of a BitTorrent host in Ethernet and WiMAX in terms of throughput, RTT, jitter, and so on as shown in Table II. The download speeds of all three WiMAX scenarios are less than 400 Kbps. The upload traffic is around 5 Kbps at best, which indicates that an SS has marginal bandwidth capacity of upload traffic in mobile WiMAX. So due to the *tit-for-tat* [12] incentive, a host in mobile WiMAX receives the pieces of the file mostly from the seeds, rather than from leechers.

The average RTT values of a host in WiMAX to its peers is around 300 to 500 ms, much higher than that of an Ethernet host. Large jitter also indicates unstable link conditions of an SS in mobile WiMAX. TCP retransmission (reTX) indicates the ratio of packets that are retransmitted on downlink. The average TCP reTX of three WiMAX scenarios is almost 9%. CINR stands for carrier to interference and noise ratio, where the higher CINR indicates the better radio link condition. Notice that the average signal quality (which is CINR) is quite stable in the static scenario. However, since the position of a host in the static scenario is fixed relatively far from the BS, the signal strength is low. An SS in the subway scenario exhibits the highest CINR on average among the tested scenarios since all the subway stations in the route have BSs and there are often repeaters in the subway tunnels. As an SS in the bus experiences poor link conditions frequently, its P2P performance is worse than that of an SS in static scenario despite its higher CINR. The cumulative distribution function of the RTT and CINR values are shown in Fig. 1.



(a) CDF of RTT (b) CDF of CINR

Fig. 1. CDF of RTT and CINR of a BitTorrent host

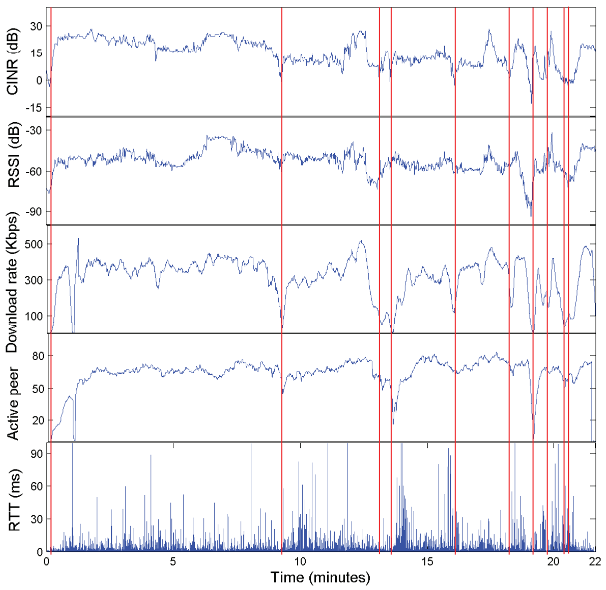
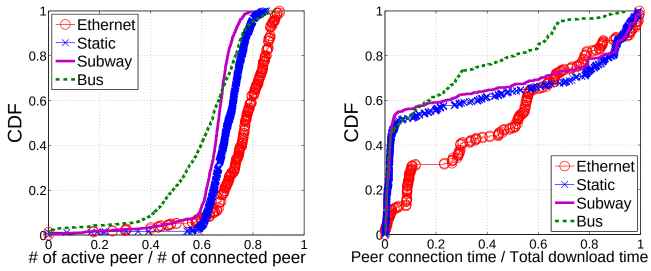


Fig. 2. Handovers affect a host in WiMAX substantially in bus scenario

B. Performance Degradation by Handovers

Handovers significantly affect the performance of SSs, especially because WiMAX adopts a break-and-make approach when an SS switches from the old BS to the new BS. We plot the various metrics over time to observe the impact of handovers in the bus route as shown in Fig. 2, where the red vertical lines indicate the handover occurrences. The XRO7000 toolkit is used to get the exact time of handovers. As we can see, a handover occurs whenever the CINR drops around 0; so 0 dB may be the handover threshold in KT's WiMAX network. The handover disruption will interrupt TCP transmissions; the retransmission timeout may expire, which in turn reduces the TCP congestion window. What is worse, the number of active peers, who are currently exchanging data with the given SS, is also reduced due to the handover disruption as shown in Fig. 2.

C. Peer Connectivity



(a) CDF of the ratio of the number of active peers to the number of total connected peers (b) CDF of the ratio of the peer connection duration to the entire file downloading time

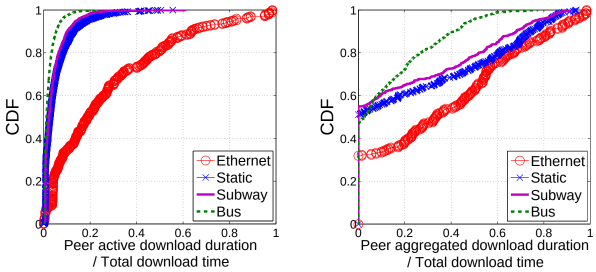
Fig. 3. P2P Peer Connectivity

The connectivity among peers is one of the most important factors in BitTorrent systems. Fig. 3(a) shows the ratio of the number of active peers of a host to the number of all the connected peers of the host, who are having connectivity with the host. The number of the connected peers increases while downloading the file is going on since the host periodically updates its peer list by contacting the tracker that returns the subset of the latest peers. The number of connected peers decreases when the host is choked by peers. The number of the active peers varies more widely than the number of the connected peers since the former is directly affected by link conditions. The bus scenario shows the smallest and yet most unstable ratio, because of the highly fluctuating status of the wireless link while the bus moves. However, the wireless link of a host in the subway is almost as good as the one in the static scenario since the signal quality in subway is stable.

We also measure the ratio of the duration of a peer connection to the entire duration of file downloading, which is shown in Fig. 3(b). More than half of peer connections suffer from very short duration. Especially, the peer connection duration in the bus scenario is much shorter than those in other scenarios.

D. Download Connectivity Stability

We analyze the downlink throughput of a host. To quantify the download throughput stability, we define two metrics: **active download duration** and **aggregated download duration**. The active download duration is the interval from the moment a byte is transmitted from a peer to the moment when there is no transmitted byte from the peer, where transmitted bytes are calculated at the period of 0.5 second. (*Vuze* logs record at 0.5-second intervals.) It often takes place that a host receives data from the same peer intermittently. For this case, the aggregated download duration of a peer refers to the sum of the active download durations of the same peer. Thus, both metrics indicate the stability of connectivity amongst peers. Note that they are normalized to the entire file downloading time. As shown in Fig. 4(a), the active download durations of a host from its peers in the three scenarios (static, subway, bus in the mobile WiMAX network) are much shorter than that of an Ethernet host. In particular, a host in the bus scenario has the worst performance that almost 90% of the active download durations are shorter than 5% of the entire file download time. Fig. 4(b) reveals that almost half of the connected peers transmit little or no data to the host.



(a) CDF of the ratio of the active download duration to the entire file downloading time (b) CDF of the ratio of the aggregated download duration to the entire file downloading time

Fig. 4. Evaluation of P2P Download Stability

E. Control Message Overhead

In BitTorrent, peers and the tracker should exchange control packets for their operations, especially to obtain the information about the pieces of the requested file to be received from multiple peers. We measure the overhead of the control packets, which is defined as the ratio of the number/bytes of the control packets to the number/bytes of all packets. As shown in Table III, the WiMAX host generates more control packets per data packet than the Ethernet host since unstable connections among peers make the WiMAX host exchange more control packets. Also, we classify all the BitTorrent control packets[3] of a host in each scenario and calculate the ratio of the number of each control packet to the whole control packets in Table III. In particular, the "request" and "have" control packets are much more generated by the WiMAX host than the Ethernet host, which indicates the WiMAX host tries to keep up with its peers despite its poor link condition. Even though the WiMAX host generates more control packets, the instability and high RTT values of the connections to its peers make such efforts inefficient.

IV. CONCLUSION

In this paper, we comprehensively measured and analyzed the BitTorrent performance of hosts in a mobile WiMAX network, which will be the basis for the redesign of P2P operations in the challenging environments in terms of link instability. Based on measurements of BitTorrent performance over mobile WiMAX, we reach the following conclusions:

[3]http://www.bittorrent.org/beps/bep_0003.html

TABLE III
OVERHEAD OF BITTORRENT CONTROL PACKETS (%)

	Ethernet	Static	Subway	Bus
by number of packets	4.68	7.80	7.81	8.36
by number of bytes	3.98	5.65	5.46	5.66
Choke	1.34	0.98	0.94	0.95
Unchoke	8.53	5.15	5.44	5.21
Interested	8.15	4.45	4.28	4.24
Not interested	8.82	4.32	4.29	3.78
Have	14.33	20.76	21.63	22.77
Bitfield	7.92	4.21	3.94	3.90
Request	23.11	32.54	33.41	32.28
Piece	18.94	22.04	20.49	20.18
Cancel	8.85	5.56	5.57	6.69

(1) links in mobile WiMAX are quite unstable due to signal strength fluctuation and handovers, and hence connections amongst peers are usually in poor conditions and often broken; (2) the above link instability makes download performance degraded since TCP achieves poor throughput due to the congestion control mechanisms; (3) control packets are unnecessarily increased and waste bandwidth. Overall, the current BitTorrent cannot adapt to the mobile WiMAX environments well. How to modify P2P protocols and algorithms in mobile networks will be the crucial task.

ACKNOWLEDGMENT

This work was supported by NAP of Korea Research Council of Fundamental Science and Technology and the ITRC support program [NIPA-2010-C1090-1011-0004] of MKE/NIPA. The ICT at Seoul National University provided research facilities for this study.

REFERENCES

[1] CISCO, "Cisco visual networking index: Global mobile data traffic forecast update, 2009-2014," CISCO, Tech. Rep., 2010.
[2] D. Kim, H. Cai, M. Na, and S. Choi, "Performance measurement over mobile wimax/ieee 802.16e network," in *IEEE WoWMoM*, 2008.
[3] S. Woo, K. Jang, S. Kim, S. Cho, J. Lee, Y. Lee, and S. Moon, "Best-case wibro performance for a single flow," in *ACM MICNET*, 2009.
[4] X. Wang, H. Kim, A. V. Vasilakos, T. T. Kwon, Y. Choi, S. Choi, and H. Jang, "Measurement and analysis of world of warcraft in mobile wimax networks," in *ACM NetGames*, 2009.
[5] M. Han, Y. Lee, S. Moon, K. Jang, and D. Lee, "Evaluation of voip quality over wibro," in *PAM*, 2008.
[6] C. M. Huang, T. H. Hsu, and M. F. Hsu, "Network-aware p2p file sharing over the wireless mobile networks," *IEEE JSAC*, vol. 25, no. 1, 2007.
[7] H. Wu, C. Shi, H. Chen, X. Zhou, and C. Gao, "An architecture for mobile p2p file sharing in marine domain," in *IEEE PerCom*, 2008.
[8] S. Liu, W. Jiang, and J. Li, "Architecture and performance evaluation for p2p application in 3g mobile cellular systems," *WiCOM 2007*.
[9] "http://www.myungmin.com/," *KT WiBro Modem*.
[10] "http://www.vuze.com/," *Vuze*.
[11] "http://www.xronet.com/," *XRONet*.
[12] "http://en.wikipedia.org/wiki/tit_for_tat," *Tit-for-Tat*.