
Characterizing the Gaming Traffic of World of Warcraft: From Game Scenarios to Network Access Technologies

**Xiaofei Wang, Ted “Taekyoung” Kwon, and Yanghee Choi, Seoul National University
Min Chen, Huazhong University of Science and Technology
Yan Zhang, Simula Research Laboratory and University of Oslo**

Abstract

Over the past decade, massively multiplayer online role-playing games have become very popular and profitable, and they have attracted millions of people to play for fun in the virtual world. In this article, we first identify the fundamental challenges in MMORPG traffic analysis. Then, we mainly focus on the impact of the application scenarios and the network access technologies on the online gaming traffic. We carry out measurements and analysis of the traffic patterns of World of Warcraft (WoW) in three distinct gaming scenarios: downtown, hunting, and battling. Also in order to evaluate the impact of different network access technologies, we connect to the Internet through Ethernet, Wi-Fi, and mobile WiMAX. Based on the captured traces, we measure WoW traffic in terms of bandwidth consumption, delay, packet loss rate, packet size and packet inter-arrival time. Our real-trace analysis shows that the MMORPG traffic is highly dynamic with various game scenarios and the network performance is strongly affected by the network access technologies. To facilitate the simulation, we also develop a generalized traffic model by characterizing the MMORPG traffic dynamics.



Over the years, the online gaming industry has rapidly attracted millions of people to play [1]. Online gaming connects all players all over the world together for fun and excitement, and thus has been regarded as one of the most profitable and popular Internet services. There are various types of online games in the market, such as casual games, shooting games, strategy games, and massively multiplayer online role-playing games (MMORPGs). In terms of the number of users, MMORPGs are the most popular online games. In an MMORPG, players are represented as virtual avatars who can interact with each other for the exploration of a virtual world, which is normally based on historical or mysterious stories. The player at the client side controls all actions of an avatar with a keyboard and a mouse (e.g., running, talking, casting skills, and fighting), while the controlling data is exchanged between the game client and the server over the Internet.

As the number of players of online games has been rapidly increased, the network traffic generated by online games shares about 5 percent of Internet traffic [2], which is still growing very fast. There are many challenges imposed by the MMORPG traffic due to its unique operating environments.

A large number of players: The most well-known MMORPG, World of Warcraft (WoW), has attracted more than 10 million players. Such a huge number of players poses considerable pressure on the provision of scalable services.

Tremendous data amount: The amount of data generated

by a large number of players is quite huge. And most time-sensitive game data require reliable transmission mechanisms to guarantee the quality of service (QoS), especially at peak hours.

Diverse roles and activities: In an MMORPG there are various types of avatars, which can have different roles and activities [3]. At any time, the information and actions of any avatar will have to be disseminated to all other nearby avatars, which indicates a high volume of generated gaming traffic with dynamic characteristics [4, 5]. Different kinds of traffic patterns are generated depending on the scenarios, all of which are mixed in the virtual game world, as shown in Fig. 1.

Network access technologies: Over the last decade, players mostly accessed online games via wired links (e.g., dial-up, integrated services digital network [ISDN], asymmetric digital subscriber line [ADSL]). Recently, increasing numbers of players are accessing games through wireless (e.g., Wi-Fi) and mobile networks (e.g., mobile WiMAX). Wired and wireless technologies exhibit substantial differences in terms of bandwidth, data rate, and packet loss rate. Therefore, it becomes important to investigate the performance of different access technologies for gaming applications.

In the literature, there have been studies on online games focusing on network situations, such as traffic modeling [2], traffic-based player behavior identification [5], QoS evaluation for online games [6], and traffic identification [7]. As MMORPGs are kind of real-time interactive services, sufficient

network provisioning is highly desired for users to enjoy the services. There are also studies on how the network may affect the traffic of MMORPGs [3, 6, 8]. However, it is observed that two key points are ignored in the existing studies:

- The existing studies try to perform traffic analysis regardless of gaming scenarios. Hence, the impact of user interactions on traffic has been ignored. As explained in this article, we investigate three different scenarios:
 - Crowded downtown
 - Hunting in the wild
 - Battling
- There is no extensive analysis of the traffic characteristics with different network access technologies: traditional wired links, wireless networks, and mobile networks. It is very important to analyze how gaming traffic is affected by different network technologies.

Therefore, in this article, we are motivated to investigate and address the following two questions:

- How do different network access technologies affect gaming traffic?
- How do players' activities generate different gaming traffic?

As pointed out in [3], gaming traffic is mostly delivered over TCP connection in client-server mode. Due to the avatars' various behaviors in different gaming scenarios, the traffic flow dynamically varies a lot [4, 5]. Also, the traffic is significantly affected by different network access technologies [6], such as wired Ethernet, wireless WiFi, and mobile WiMAX. As illustrated in Fig. 2, the WoW gaming traffic is generated and varied by different gaming scenarios from the application layer with different packet sizes and interarrival times, while the traffic is also carried by the network access technologies (e.g., Ethernet, WiFi, and WiMAX, which have different link characteristics, and may impact the performance in terms of delay, packet loss rate, and bandwidth utilization. We organize the article as follows. We illustrate the three general game scenarios and give an overview of different network access technologies. We then focus on measurement settings and traffic analysis regarding the impact of gaming scenarios and access technologies. The conclusion of the article is then presented.

Classification of Game Scenarios in WoW

In WoW, player-controlled avatars have various *races* (orcs, dwarves, humans, undead) and *classes* (hunters, warriors, mages, rogues), all of which have different appearances, characteristics, and skills. Generally, avatars can always kill server-controlled monsters in the wild to obtain experience, gold, and items. They are able to form troops to explore in the wild and fight against strong monsters in specific dungeon areas. Furthermore, avatars in WoW can battle with other groups or troops for rewards.

WoW deploys a client-server structure, which is commonly used in MMORPG systems [2, 3]. We define the traffic from a game client to its server as an *uplink flow*, and its reverse traffic as a *downlink flow*. From the viewpoint of a single player, its avatar's behaviors generate packets in the uplink flow reporting to the server, while the information and

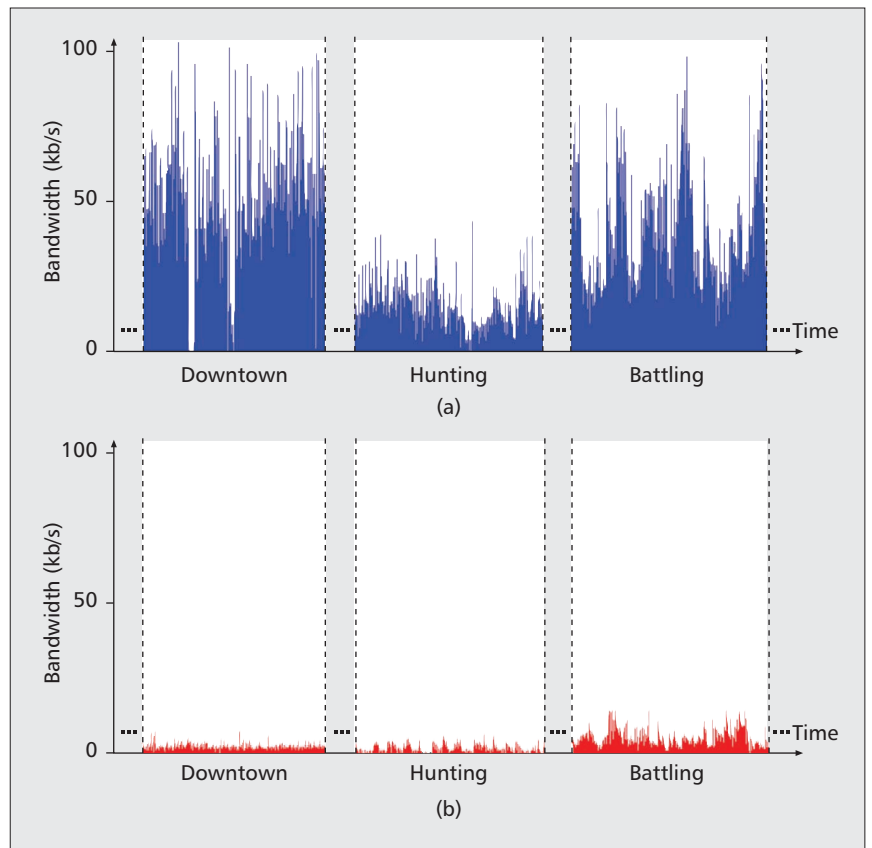


Figure 1. Some parts of traffic traces: a) parts of downlink traffic; b) parts of uplink traffic. The avatar stays downtown, and then goes out to hunt; finally, it enters the battlefields to battle.

behaviors of surrounding objects and other avatars will be packaged and delivered in the downlink flow from the server to the player. Therefore, different behaviors in different environments will generate distinct traffic patterns [4, 5]. Figure 1 shows some parts of the traffic traces of WoW gaming, and indicates that the traffic in the uplink and downlink may vary dynamically as the avatar changes scenarios. We categorize the behaviors of players in the virtual world of WoW into three general scenarios:

Downtown: In the virtual world, there are many towns and cities where avatars can get together for chatting, trading, and entertaining. In particular, the most crowded place in WoW is called Dalaran (in version 3.3.2, Korean server of WoW), where hundreds of avatars may stay there at peak hours. Generally, in the downtown, an avatar will generate a small amount of uplink traffic to upload to the server as it takes fewer actions by itself or interactions with other avatars. But in such a densely populated situation, due to the large number of avatars around, the avatar will have to download lots of data about other avatars (e.g., attributes, equipments, actions, chat words). Hence, the downlink traffic is quite high.

Hunting: In WoW, avatars go out of the cities to wild areas to kill monsters for experience, gold, tasks, and items. Monsters are controlled by servers, which realize their artificial intelligence (AI). Avatars will cast various skills to kill the monsters. As the monsters are not densely generated, an avatar normally interacts with one or two monsters at a time. Therefore, both the downlink traffic containing monster actions and the uplink traffic of the avatar behaviors are low. Note that the hunting scenario is always called Player vs. Environment (PvE).

Battling: Online gaming can be more excited when challenging enemy avatars played by other people. In WoW, at

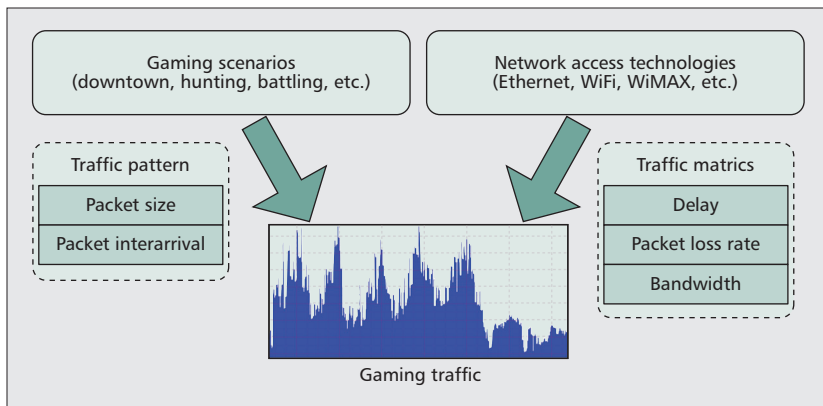


Figure 2. Gaming traffic is affected by gaming scenarios and network access technologies.

several battlefields there can be two opposite teams of tens to hundreds of members that will fight against each other to obtain certain rewards. Due to the high amount of information that needs to be exchanged among avatars with the server (e.g., casted skills, avatars' attributes and movements), both the uplink and downlink traffic are high. This battling scenario is normally called Player vs. Player (PvP). We also identify another battling case, dungeon raid, into this battling scenario. In WoW there are many instances of dungeons, and people form a team with 5 to 25 members to fight against big monsters with strong AI. Although this case should be considered like PvE scenarios, as all avatars are casting skills and moving around frequently to cooperate for killing the monsters with their highest potential, the uplink and downlink traffic are usually high. Therefore, we classify dungeon raids as battling scenarios.

Wired and Wireless Network Access Technologies

Recently, many multimedia services are likely carried in a heterogeneous environment with various network access technologies. People may play games on PCs, laptops, or handsets through different network interfaces accessing via Internet service providers (ISPs) [9]. Hence, the gaming performance relies on the link characteristics of the access networks. We mainly investigate three popular access technologies: Ethernet, WiFi, and WiMAX.

Ethernet

Ethernet, based on IEEE 802.3, is widely used for local area networks (LANs), where Ethernet users connect to the ISP by cables. Ethernet offers stable and high-speed Internet connection (e.g., up to 100 Mb/s or even 1 Gb/s) and small latency to the Internet. However, Ethernet access is restricted to stationary points without mobility support.

WiFi

WiFi is a wireless LAN (WLAN) technology based on the IEEE 802.11 standards. WiFi enabled devices such as laptops and handsets can connect to WiFi access points (APs) by wireless link at the 2.4 or 5 GHz spectrum; then the WiFi APs are connected to ISPs via LAN cables. Normally, one WiFi AP can cover up to tens of meters, within which the link capacity will be reduced as the distance increases due to the degrading channel condition and thus the coding scheme at the physical layer. Normally, WiFi can offer more than 100 Mb/s link speed (802.11n) to each connected user if the link condition is good, and the delay of the wireless communication is also quite small.

WiMAX

Over the last decade, the ever increasing demand for mobile broadband access has driven researchers and engineers to develop the mobile WiMAX technology based on the IEEE 802.16e standards.

In a WiMAX network, a base station (BS) can offer Internet access to each subscriber station (SS) with an aggregated throughput up to a few tens of megabits per second, while covering a radius of less than a few kilometers, so multiple BSs will cover metropolitan areas and support high mobility of users in cars, trains, and subway trains. An SS in the WiMAX network can keep the Internet connectivity while traveling among

the coverage of BSs by performing handovers. However, handovers may potentially disrupt the ongoing traffic. Also, the link quality of an SS will vary significantly due to wireless fading and the SS's mobility.

Note that initial measurement work [8] indicates that the TCP transmission of real-time services in a WiMAX network may be constrained by the fluctuating link quality and thus the communication delay is not low and varying, which raises questions about QoS support for delay-sensitive applications.

Traffic Measurement and Analysis

In order to collect our data sets, we played WoW on a MacBook Pro laptop with Intel Core 2 Duo T8300 CPU, 2 Gbytes RAM, and an NVIDIA 8800GT video card, running Mac OS X 10.5.4. The hardware platform is capable enough to run the WoW software at 60 frames/s; thus, we can ignore the impact of the client hardware on the gaming performance and traffic.

The Ethernet card of the laptop is a Marvell Yukon Gigabit Adapter (88E8055 Singleport Copper SA), and we directly connect the laptop by a 100 Mb/s LAN cable line to the campus network for Ethernet measurement.

For WiFi access, we connect the MacBook Pro laptop (with the embedded WiFi card, Airport Extreme, Broadcom 802.11n chip set, BCM43XX 1.0) to a WiFi AP, ipTime WiFi G504 (802.11n mode), which can theoretically support up to 150 Mb/s aggregated throughput. Then the AP is connected to the same LAN as the above Ethernet case.

For the mobile WiMAX case, we carry out our measurement in the commercial mobile WiMAX network system established by Korea Telecom (KT) in 2006, which had nearly 365,000 subscribers by the end of 2009. Following IEEE 802.16e, KT's WiMAX network adopts time-division duplex (TDD) for duplexing, and orthogonal frequency-division multiple access (OFDMA) for multiple access working at 2.3–2.4 GHz band, with the channel bandwidth of 8.75 and 10 MHz. In order to connect to the WiMAX network, we used Samsung SWT-H200K WiMAX modem, which supports throughput up to 10 Mb/s at uplink and 37.5 Mb/s at downlink.

Furthermore, for the WiMAX measurement, we conduct tests in three different routes: campus, subway, and bus. Note that the routes are illustrated in Fig. 3.

Campus: We fix the laptop with the above WiMAX modem at several locations in buildings 138, 919, and 301 on the campus of Seoul National University (SNU). There is one WiMAX BS in the center of the campus. In addition, we move by taking a shuttle bus within the campus, the trajectory of which is covered by the BS. Due to the similarity of the performance of both fixed and moving cases in the campus within one BS, we combine the results together.



Figure 3. Test routes in mobile WiMAX networks.

Subway: We travel via subway lines No. 2, No. 3, and No. 4 in the metropolitan area of Seoul, Korea. In the subway system, BSs are deployed inside subway stations, and repeaters are set up in the tunnels to enhance the signal and relay packets between SSs and BSs.

Bus: We take bus No. 501 from SNU to Seoul Station, a typical route passing several campuses, residential areas, a tunnel, a bridge over the Han River, and several mall complexes. On this route, the SS in the bus always needs to perform handovers with BSs as the bus goes through the coverage of multiple BSs.

During the measurement, we make our avatar act in WoW in the three game scenarios: downtown, hunting, and battling. In the downtown scenario, we control our avatar to randomly walk around in Dalaran. In the hunting scenario, our avatar is controlled to kill monsters constantly in the wild of the virtual world of WoW. In the battling scenario, our avatar goes to a set of battlefields and participates in many PvP fights with others; as our tester has ample experience playing WoW, our avatar continuously keeps fighting (it dies rarely) to maintain the traffic.

The test of each scenario lasted at least 30 min, and was run three to five times at different times and dates during 2009. For WiMAX access, we carry out at least three tests on each route. We collected traffic packets with Wireshark, and analyzed the traces by the tcpdump and TCPTrace tools. In total, we obtained traffic traces of 1.8 million packets, with around 57 h game play. All of the gaming traces via Ethernet, WiFi, and WiMAX are shared on the Internet as an open resource for the research community (http://crawdad.cs.dartmouth.edu/snu/wow_via_wimax).

Traffic Metrics

In this section, we adopt three performance metrics to evaluate the impact of network access technologies with respect to bandwidth consumption (or, interchangeably, utilization), delay, and packet loss rate.

Bandwidth Consumption — In order to examine how much bandwidth of the access link is consumed by WoW traffic, we compare the maximal bandwidth consumption of traffic peaks (uplink in the battling scenario and downlink in the downtown scenario) in different access technologies. As shown in Fig. 4a, WoW is not a bandwidth-hungry application, consuming not high bandwidth, at the most about 80 kb/s at uplink and 420 kb/s at downlink. All network access technologies can carry the traffic with ease normally. But in WiMAX cases, especially the bus case, the maximal bandwidth is smaller than that in the other cases, mainly because of the large amount of packet retransmissions or traffic congestion due to poor link condition and handovers. When the link quality is not good, the degraded demodulation and coding scheme of WiMAX links cannot handle a large traffic load.

Furthermore, due to the global cool down system of WoW, which is currently popularly applied in many MMORPGs, one avatar cannot cast more than one skill every 1 to 1.5 s, so the uplink traffic can be much lower. In this regard, we conclude that the traffic of the WoW is small, and all access technologies techniques can easily support it, unless the gateway or the BS is congested, the signal quality is poor in the WiFi and WiMAX networks, or there are extensive packet bursts at peak hours.

Delay (Round-Trip Time) — As MMORPGs have inherently real-time interactions, users will be unsatisfied with the performance if the responses of actions are delayed. Therefore, a critical metric for evaluating online gaming is the delay, represented as the round-trip time (RTT). The RTT is defined as the time duration from the moment at which a TCP data packet is sent from the client to the server until the moment at which a corresponding TCP acknowledgment packet arrives at the client.

Furthermore, online game players tend to be more sensitive to large delay variations than to large delays [6]. Therefore, we investigate the RTTs of all TCP data packets of WoW traffic and their variation (jitter) in Fig. 4b. The blue boxes

show the boundary of the 25th and 75th percentiles of the RTTs, and RTT values are plotted within the whisker in black lines if they are smaller than $q3 + 1.5 \cdot (q3 - q1)$ and larger than $q1 - 1.5 \cdot (q3 - q1)$, where $q1$ and $q3$ are the 25th and 75th percentiles, respectively.

Figure 4b shows that the RTTs of Ethernet and WiFi access technologies are around 30–60 ms, which are quite low and satisfactory for experiencing the game. This is also the main reason players mainly use Ethernet and WiFi for online gaming. In addition, the RTT variations of the two cases are small, indicating stable link quality. For WiMAX, the delay performance is worse than Ethernet and WiFi, since uplink traffic should make a bandwidth reservation first; also, there are fading and handovers in mobility cases. Compared to the campus case, the WoW traffic in the subway and bus cases suffers from higher RTTs. Particularly, the SS in the bus has the highest RTTs and variation. In outdoor environments, the signal experiences fading, so physical layer coding schemes are adaptively changed based on signal quality. Handover also happens frequently, which enlarges the RTTs further. In the subway case, since there is a BS at every subway station, the good signal quality makes the RTTs smaller than in the bus case, but handovers still may degrade the performance to a certain degree.

Packet Loss Rate — The loss of TCP packet significantly affects the gaming performance [6] mainly due to the TCP retransmission mechanism. We investigate the ratio of the retransmitted packets in both downlink and uplink to check the packet loss rate, which is shown in Fig. 4c.

There is almost no packet loss in both the uplink and downlink in the Ethernet access due to the stable cable connection. In Wi-Fi case, there are marginal packet losses due to the interference and collision. However, in contrast, the packet loss rate in WiMAX case is relatively much higher, almost up to 0.5 percent uplink and 3 percent downlink (bus case). Wireless links in mobile WiMAX networks suffer from fading in outdoor environments and handovers, so the packet loss rate in the bus case has the highest value.

A large number of lost packets and retransmissions will degrade TCP performance severely and bring unsatisfactory experience to users in WiMAX networks. How to reduce the packet loss ratio in mobile WiMAX networks is currently a hot issue in the newest 802.16m standard with enhanced QoS support in the medium access control (MAC) layer to further guarantee the reliable transmission of packets.

Traffic Pattern

We study the traffic pattern in terms of packet size and packet interarrival time, which characterize WoW traffic from both spatial and temporal perspectives.

Packet Size — Figure 5a shows the cumulative distribution function (CDF) of downlink packet sizes in different gaming scenarios. As the statistics of captured traffic via the Ethernet, WiFi, and WiMAX are nearly similar, due to the space limitation, we only plot the results of WiFi networks. In the downtown and battling cases, packet sizes are larger than they are in hunting because the action information of more avatars and monsters is transmitted. Moreover, in downtown and battling scenarios, 40 percent and 20 percent of packets are with the maximum packet size (1460 bytes excluding TCP/IP header), respectively. It could be explained with the TCP maximum transmission unit (MTU) limitation. All of the packets from applications that have sizes larger than a certain threshold will be fragmented into segments according to the TCP MTU limitation. Therefore, a large number of packets with the maxi-

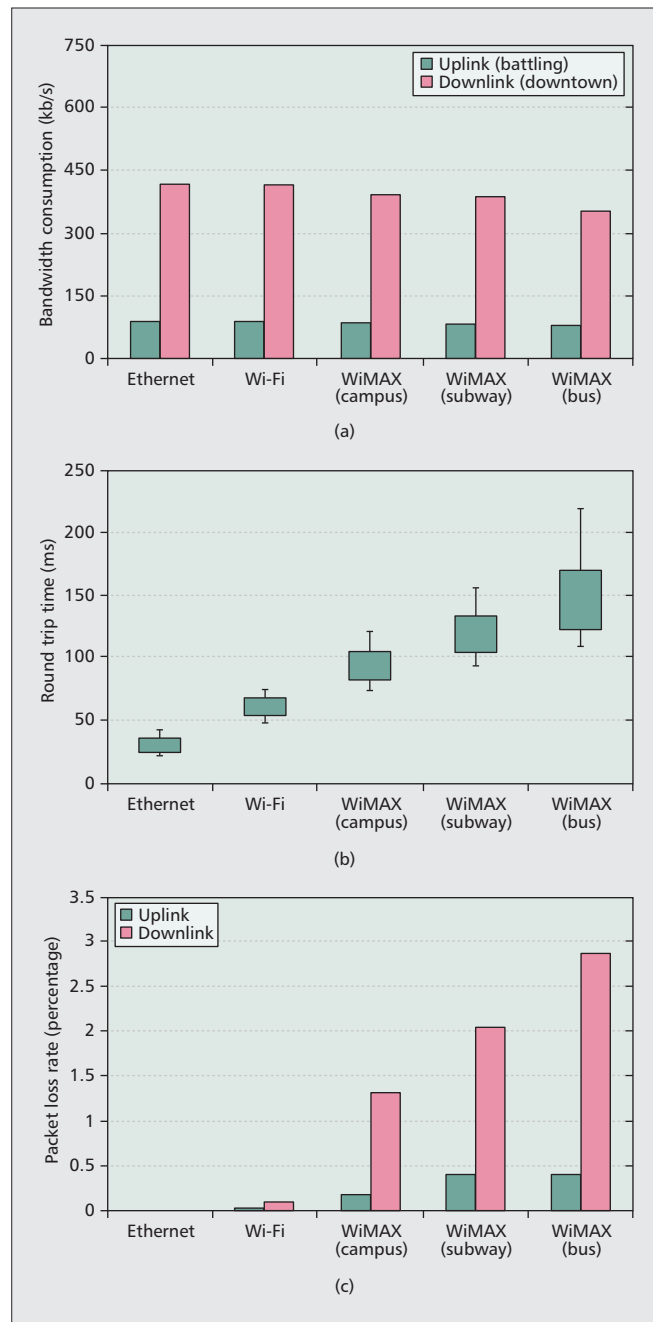


Figure 4. Traffic performance metrics: a) bandwidth consumption; b) RTT with variation; c) packet loss rate.

mal size appearing in the figure indicate the fact that the server sends a huge amount of data (e.g., in the downtown and battling scenarios).

Figure 5b shows the CDF distribution of the uplink packet sizes. One interesting observation is the staircase happens around the size of 10, 14, 36, and 52 bytes in all scenarios. This indicates that WoW's uplink flows mostly have several types of packets depending on the actions of the avatars (e.g., movement, skill casting, and chatting).

Packet Interarrival Time — Packet interarrival time is the time interval between two consecutive packets from the WoW client application or from the WoW server. Figure 6a shows the CDF of packet interarrival times in downlink. We observe that the packet interarrival times in the downtown and battling scenarios are much shorter than those in hunting. This

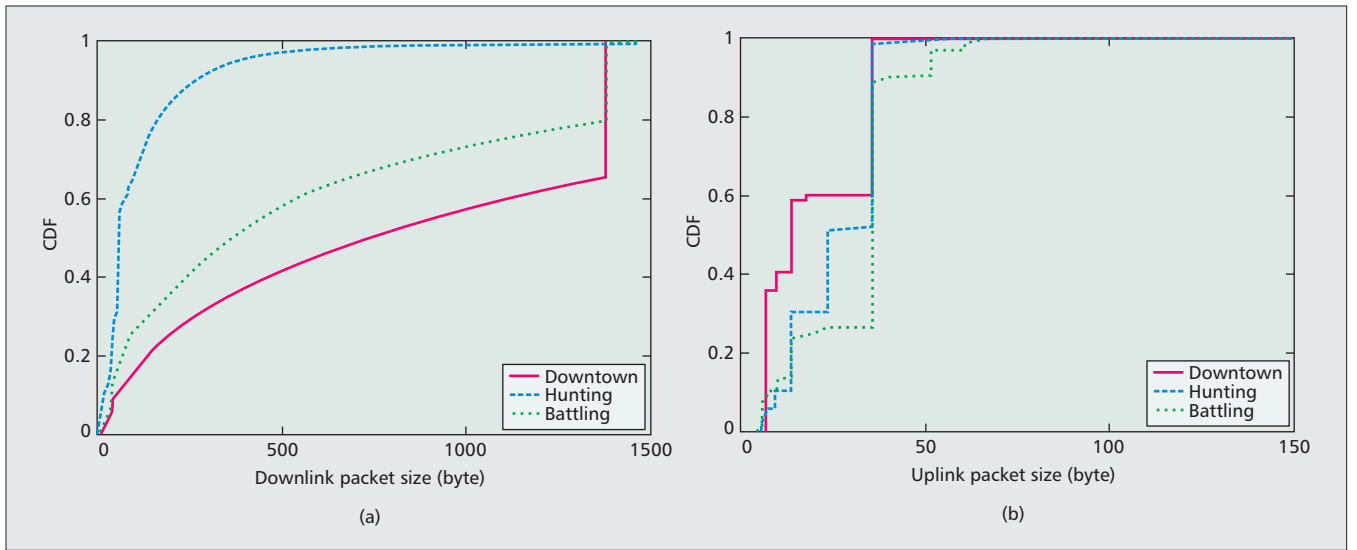


Figure 5. CDFs of packet size of downlink and uplink (byte): a) downlink packet size; b) uplink packet size.

indicates that the information of downtime and battling scenarios is large and frequently generated due to large number of nearby avatars and their intensive activities. Another interesting observation is that there are many packets arriving at the client with interarrival times of nearly 0 ms, which again indicates the continuous transmission of packets due to the MTU limitation. Most interarrival times fall within the range of 0.1–0.3 s, which is probably the mandatory interval of data exchange as required by the WoW application.

Figure 6b shows the uplink packet interarrival time. Similarly, packet exchange frequency in the hunting scenario is smaller than those in the downtime and battling scenarios. There is a somewhat sharp rise around 0.5 s, which indicates that the client has to always send some packets to the server at 0.5 s intervals, probably due to the security and stability requirements from the server side.

Modeling the Traffic

Based on the measurement results in the previous sections, we model packet sizes and packet interarrival times of WoW traffic for both uplink and downlink in the three gaming scenarios. In the modeling of traffic characteristics, we adopt the

Weibull distribution, which has been widely used for statistical modeling of Internet traffic [2]. The Weibull distribution has two adjustable parameters, λ for controlling the scale and k for controlling the shape for the curve of probability distribution function (PDF). The PDF of the Weibull distribution, $f(x; \lambda, k)$, for $x \geq 0$ is defined as

$$f(x; \lambda, k) = \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k}$$

Fitting the Packet Sizes and Interarrival Times — Let M denote the maximum packet size. The percentage of the maximum size packets can be an important factor to characterize the traffic pattern. Let β be the percentage of these packets, where $\beta \in [0, 1]$. From the analysis on our trace data, β of uplink traffic is 0 for all the scenarios. For the downlink flows, the values of β in the downtime, battling and hunting scenarios are 0.35, 0.20, and 0.01, respectively. After separating these packets, we fit the remaining ones into the Weibull distribution by finding out appropriate λ and k . Thus, the formula of the packet size generator is given by the following piecewise PDF:

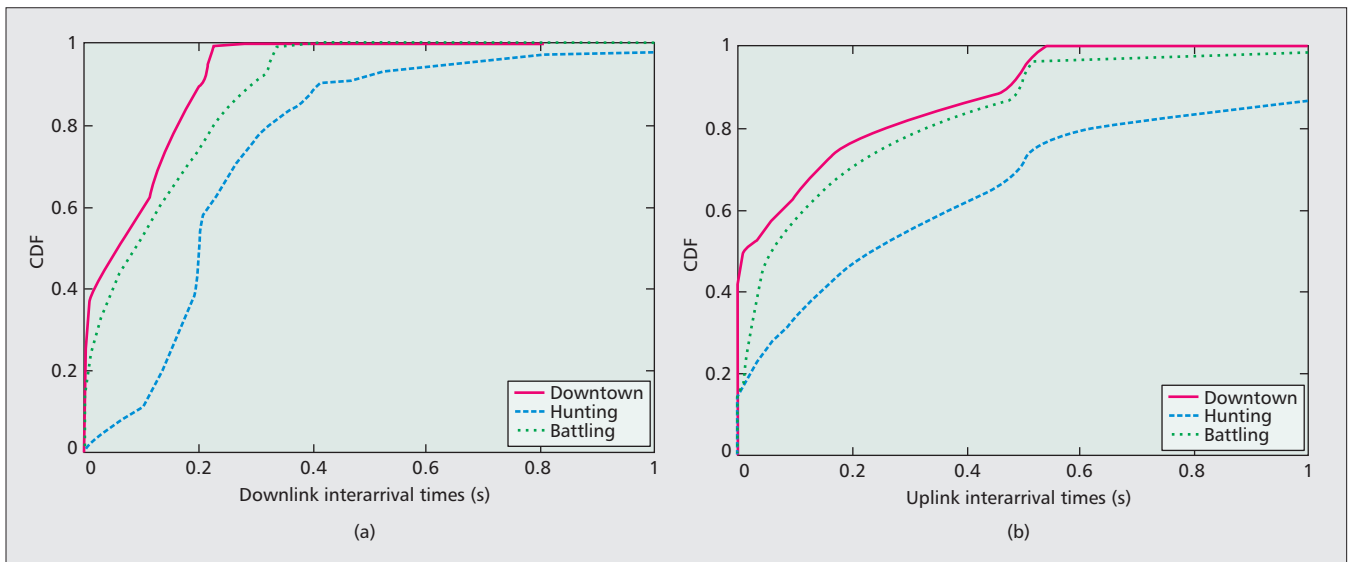


Figure 6. CDFs of packet inter-arrival times of downlink and uplink: a) downlink interarrival; b) uplink interarrival times.

$$f(x) = \begin{cases} \beta, & x = M \\ (1-\beta) \cdot \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k}, & x \in [0, M) \end{cases}$$

To model the packet interarrival time, the Weibull distribution is directly employed, and we can find out appropriate λ and k parameters.

Results of Modeling — Due to space limits, we only show the fitting values of λ and k in the case of the Wi-Fi access technology in Table 1. The modeling and fitting results can be used to synthetically generate practical WoW traffic based on the dynamics of user activities and link conditions in simulation software, by implementing the parametric traffic generator with related Weibull random variables.

Conclusions and Future Work

MMORPG traffic has distinct characteristics due to the large number of players and diverse gaming scenarios; also, network access technologies can impact the traffic in terms of bandwidth, delay, and packet loss rate. We carried out measurement and analysis of WoW traffic in different gaming scenarios over the Ethernet, Wi-Fi, and mobile WiMAX networks, and investigated how game scenarios affect the traffic patterns and link access technologies result in different traffic performance. Our comprehensive study on the WoW traffic can help the game designers and network operators to offer better gaming services to players. In the future, the following issues will be important for in-depth gaming traffic analysis, and thus need further investigation:

Classification: Classification of the gaming traffic [7, 10] is important for network flow control, resource provisioning and so on. Improving the traditional port-based, host-based, pattern-based, and behavior-based classification methods, and designing new methods for more precise identification of the dynamic gaming traffic are necessary but still challenging.

Fairness and scheduling: Traffic congestion at the intermediate gateways or BSs of mobile networks always has a significant impact on real-time online gaming traffic. Considering the fairness and priority of gaming traffic compared to other concurrent traffic flows, more effective scheduling algorithms are highly demanded in order to guarantee the QoS of gaming services.

Scalability: Facing the emerging heterogeneous network environment, where a large number of players can access the games via Ethernet, Wi-Fi, WiMAX, and other fourth-generation networks, the scalability of the gaming service should be seriously considered. Game servers, game clients, and the communication schemes should be cognitive and aware of the network accesses as well as the capability of gaming devices; thus, gaming traffic can be optimized (e.g., removing less important information when the network link condition is not good), in order to enhance the gaming experience of players.

Acknowledgement

This work was partly supported by the IT R&D program of MKE/KEIT (10035245: Study on Architecture of Future Internet to Support Mobile Environments and Network Diversity). It was also supported by the Ministry of Knowledge Economy (MKE), Korea, under the Information Technology Research Center (ITRC) support program supervised by the National IT Industry Promotion Agency (NIPA-2011-(C1090-1111-0004)).

		Packet size		Interarrival time	
		Scale (λ)	Shape (k)	Scale (λ)	Shape (k)
Downtown	DL	430.263	1.007	0.050	0.492
	UL	22.709	1.578	0.042	0.367
Hunting	DL	109.838	1.001	0.280	1.300
	UL	29.843	2.255	0.283	0.543
Battling	DL	344.545	0.940	0.104	0.763
	UL	35.442	1.983	0.112	0.532

Table 1. Weibull distribution parameters for MMORPG traffic pattern (Wi-Fi case).

References

- [1] D. C. Williams and S. S. Seteroff, "Beffair: A Case Study on The U.S. Internet Gaming Market," *Gaming Law Review and Economics*, vol. 13, no. 1, 2009, pp. 41–49.
- [2] P. Svoboda, W. Karner, and M. Rupp, "Traffic Analysis and Modeling for World of Warcraft," *Proc. IEEE ICC*, Glasgow, U.K., 2007.
- [3] K. T. Chen, P. Huang, and C. L. Lei, "Game Traffic Analysis: An MMORPG Perspective," *Elsevier Computer Networks*, vol. 25, no. 16, 2006, pp. 3002–23.
- [4] G. Szabo, A. Veres, and S. Molnar, "On the Impacts of Human Interactions in MMORPG Traffic," *J. Multimedia Tools and Apps.*, vol. 45, no. 1–3, 2009, pp. 133–61.
- [5] G. Szabo, A. Veres, and S. Molnar, "Effects of User Behavior on MMORPG Traffic," *Proc. IEEE Int'l. Conf. Commun. (ICC)*, Dresden, Germany, 2009.
- [6] K. T. Chen *et al.*, "On the Sensitivity of Online Game Playing Time to Network QoS," *Proc. 25th IEEE INFOCOM*, Barcelona, Spain, 2006.
- [7] Y. Han and H. Park, "Game Traffic Classification Using Statistical Characteristics at the Transport Layer," *ETRI J.*, vol. 31, no. 1, 2010, pp. 22–32.
- [8] X. Wang *et al.*, "Measurement and Analysis of World of Warcraft in Mobile WiMAX Networks," *Proc. ACM 8th SIGCOMM & SIGMM Annual Wireless Network and Sys. Support for Games (NetGames)*, Paris, France, 2009.
- [9] S. Lian and Y. Zhang, "Protecting Mobile TV Multimedia Content in DVB/GPRS Heterogeneous Wireless Networks," *J. Universal Computer Science*, vol. 15, no. 5, 2009, pp. 1023–41.
- [10] W. Wang, S. Gombault, and T. Guyet, "Towards Fast Detection Intrusions: Using Key Attributes of Network Traffic," *Proc. 3rd Int'l. Conf. Internet Monitoring and Protection (ICIMP)*, Bucharest, Romania, 2008.

Biographies

XIAOFEI WANG (dobby@mmlab.snu.ac.kr) is a Ph.D. candidate in the Multimedia & Mobile Communication Laboratory, School of Computer Science and Engineering (CSE), Seoul National University (SNU), Korea. He received the B.S. degree in the Department of Computer Science and Technology of Huazhong University of Science and Technology (HUST) in 2005 and M.S. degree from the School of CSE at SNU in 2008. His current research interests are in the areas of mobile traffic analysis, service evaluation in wireless mobile networks, and content sharing in mobile content-centric networks.

MIN CHEN [SM] (minchen@ieee.org) is a professor at Huazhong University of Science and Technology, he was an assistant professor in School of Computer Science and Engineering at SNU. He was a research associate in Dept. of Computer Science at the University of British Columbia (UBC), and has worked as a post-doctoral fellow in the Department of Electrical and Computer Engineering at UBC for three years since Mar. 2009. He has published more than 120 technical papers. He is the sole author of a textbook, *OPNET Network Simulation* (Tsinghua University Press, 2004). He serves as Editor or Associate Editor for *Wiley I. J. of Wireless Communication and Mobile Computing*, *IET Communications*, *Wiley I. J. of Security and Communication Networks*, *Journal of Internet Technology*, *KSII Transactions on Internet and Information Systems*, and *International Journal of Sensor Networks*. He is a Managing Editor for *International Journal of Autonomous and Adaptive Communications Systems*. He also serves as the corresponding guest editors for several international journals, such as *ACM/Springer Mobile Networks and Applications (MONET)*, *International Journal of Communications System (IJCS)*.

YAN ZHANG (yanzhang@ieee.org) received a Ph.D. degree from Nanyang Technological University, Singapore. From August 2006, he is working with Simula Research Laboratory, Norway. He is currently senior research scientist at Simula Research Laboratory, Norway. He is an associate professor (part-time) at the

University of Oslo, Norway. He is a regional editor, associate editor, on the editorial board, or guest editor of a number of international journals. He is currently serving as Book Series Editor for the book series on *Wireless Networks and Mobile Communications* (Auerbach Publications, CRC Press, Taylor & Francis Group). He serves as Organizing Committee Chair for many international conferences, including AINA 2011, WICON 2010, IWCMC 2010/2009, BODYNETS 2010, BROADNETS 2009, ACM MobiHoc 2008, IEEE ISM 2007, and CHINACOM 2009/2008. His research interests include resource, mobility, spectrum, energy, and data management in wireless communications and networking.

TED "TAEKYOUNG" KWON (tkkwon@mmlab.snu.ac.kr) has been an associate professor in the School of Computer Science and Engineering, SNU, since 2008. Before joining SNU, he was a postdoctoral research associate at the University of California at Los Angeles (UCLA) and at City University of New York (CUNY). He obtained B.S., M.S., and Ph.D. degrees from the Department of Computer Engineering, SNU, in 1993, 1995, and 2000, respectively. During his graduate program, he was a visiting student at IBM T. J. Watson Research Center and at the University of North Texas. His research interest lies in sensor networks, wireless networks, IP mobility, and ubiquitous computing.

YANGHEE CHOI (yhchoi@snu.ac.kr) received his B.S. in electronics engineering from SNU, his M.S. in electrical engineering from Korea Advanced Institute of Science and Technology, and his D.Eng. in computer science from the Ecole Nationale Supérieure des Telecommunications (ENST), Paris, France, in 1975, 1979, and 1984, respectively. Before joining the School of Computer Science and Engineering, SNU, in 1991, he was with the Electronics and Telecommunications Research Institute (ETRI) from 1977 to 1991. He was at Centre National d'Etude des Telecommunications (CNET), Issy-les-Moulineaux, France, from 1981 to 1984. He was also a visiting scientist at IBM T. J. Watson Research Center for the year 1988–1989. He now leads the Multimedia and Mobile Communications Laboratory at SNU. He was President of the Open Systems and Internet Association of Korea, and of the Korean Institute of Information Scientists and Engineers. He was also dean of the Graduate School of Convergence Science and Technology, and President of the Advanced Institutes of Convergence Technology. He is a Fellow of the Korean Academy of Science and Technology (KAST) and the National Academy of Engineering of Korea (NAEK). He is Chair of the Special Committee on Convergence Technology of KAST. He is also a member of the Korean President's Council on Informatization Strategies (CIS). He is now Chair of the Future Internet Forum. His research interests lie in the field of future Internet, multimedia communications, and wireless networking.