Player Behavior and Traffic Characterization for MMORPGs: A Survey

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Abstract Massively Multiplayer Online Role-Playing Games (MMORPGs) are one of the most exciting and most rapidly expanding genres of online games. This survey presents state of the art and current research efforts in measuring, characterizing, and modeling the player behavior and the network traffic, as well as the relationships between them. We also tabulate the measurement, modeling and analysis results regarding network traffic and player behavior found in literature, with key information regarding each dataset. Finally, we list currently confirmed claims and open research questions in the area of MMORPGs.

Keywords Games · MMORPGs · Network traffic · User behavior

1 Introduction

The genre of Massively Multiplayer Online Role-Playing Games (MMORPGs) has a rather long history, dating back to *Adventure*, the first widely used adventure game released in 1975, and the first multi-user dungeon (MUD) released in 1978. The term MMORPG was coined in 1997 by Richard Garriott, the creator of *Ultima Online*, while previously this game genre was generally referred to as "graphical MUDs" [17].

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Currently, there are three main business models for MMORPGs, namely: a) a subscription based model, which involves paying a monthly fee to play the game (e.g., *World of Warcraft* (WoW)), b) free to play model, which uses micro transactions for purchasing virtual items or abilities for real money (e.g., *Runes of Magic*), and c) retail model, which involves separate purchases for the game, and for each additional zone and/or content in the virtual world (e.g., *Guild Wars*). A wide variety of model options makes it difficult to estimate the number of active MMORPG players. According to *NewZoo*, an international market research and consulting firm focused on the game industry, the estimated number of MMOG players (including all types of MMOGs) in the USA alone is over 50 million [54]. For MMORPGs using the subscription based business model, a web portal MMOData.net reports a strong growth trend in the number of subscribers since late 1990s, and estimates their number rising to over 20 million by 2011 [31]. What is certain is that MMORPGs are becoming more and more popular among players, and hence also among game publishers, thanks to growing revenues. Market significance and the need for innovative solutions also contribute to a growing interest in MMORPG related research.

Research in the area of MMORPGs is progressing in several directions, aiming to solve their inherent problems such as scalability, efficiency, and quality of service. All commercial MMORPGs are based on client-server architecture which, combined with a high number of users, results in server scalability issues. To alleviate scalability problems, new architectures, combined with virtual world partitioning algorithms, and scalability techniques have been proposed. Network traffic produced by MMORPGs is another topic of increasing significance, as it constitutes a major portion of overall gaming traffic in the Internet. Also, network traffic in MMORPGs is very sensitive in terms of network Quality of Service (QoS). Player behavior is another challenging aspect of MMORPGs, as it has significant impact on both the server and the network load. Here, virtual world partitioning algorithms and area of interest management play a significant role. Player behavior is also studied for the purposes of game design and marketing (e.g., for estimation of player churn).

The focus of this survey is on research dealing with player behavior and network traffic.While there is a significant amount of literature related to network traffic in MMORPGs, a comprehensive survey of research work in the area is missing. Action games, in particular the First Person Shooter (FPS) games, are covered by a recent survey by Ratti, Hariri, and Shirmohammadi [63]. Also worth mentioning is a comparative traffic analysis from the genre characteristics perspective by Che and Ip [18], which includes selected MMORPGs in the comparison. Their work provides very nice graphical representations of the relationships between the ranges of packet sizes and packet inter-arrival times (IATs) for eight MMORPGs. Also, cumulative distribution functions (CDFs) of both server and client packet sizes and packet IATs for four MMORPGs are presented, which enable an easy comparison. While that survey covers several game genres and cross-genre comparisons (e.g., FPS traffic has much lower packet inter-arrival times, and smaller packet sizes than MMORPGs), our work differs from theirs in that we focus exclusively on MMORPGs, and aim to provide deeper understanding of network traffic by relating it to application-level player behavior. We also summarize the characteristics of various MMORPGs observed at the network level, and try to identify generic, genre specific characteristics of MMORPGs, from those specific to a particular game, its architecture and mechanics.

The main contribution of this paper is an overview of current research work related to MMORPGs in the aspects of network traffic and player behavior, and the relationship between them. Along these lines, the paper is structured into three sections. After the first, introductory section, network traffic issues are covered in the second section. In that section we provide the state of the art review in the area of network traffic analysis and modeling for MMORPGs. We list and explain the key terms and traffic parameters of interest, which are discussed in the remainder of the paper. In addition, we provide a summary of network traffic measurements, with focus on the measurement process, characteristics of obtained datasets, and main results.

The third section of the paper deals with player behavior and session characteristics. We explain main parameters of interest and focus on patterns of player behavior which appear in various MMORPGs, aiming to identify generic aspects of player behavior to allow comparison. Measurements results regarding player behavior found in literature are tabulated with respect to the measurement process, dataset characteristics, and relevant references regarding a specific dataset, aiming to provide the right pointers to the readers who need datasets for comparison and verification purposes, as well as for building new traffic models. We provide a summary table describing the player behavior properties studied by various research groups and the results they obtained.

In addition to these two views of MMORPGs (player behavior and network traffic), in the fourth and final section of the paper we explore the relationship between them, and especially the *application aspect* of the virtual world [49], which poses the question: how does an interaction at the application (user) level affect the communication characteristics? While it is known that player behavior, in general, has significant impact on MMORPG network traffic characteristics [67, 73, 24], new research approaches are needed to better understand and model the traffic. Thus, the player behavior is studied at the level of a single flow, as well as at the aggregated traffic level. We present the state of the art review in this area, as well as explain and describe the main parameters of interest.

The survey presented in this paper is also motivated by the challenge to provide a comprehensive introduction to a new researcher in the field. It is our goal to clarify fundamental issues and concepts, and help newcomers avoid common measurement and analysis errors and misconceptions which may arise from different measurement techniques.

For professionals in the field, this survey may assist developers and testers of communication infrastructure, equipment, and software for load generation and testing. The results provided in this survey may also benefit Internet Service Providers (ISPs) for better planning and dimensioning the links for MMORPGs, and classifying the network traffic properly which is especially important because of the high QoS demands by these games. A striking recent example was a customer revolt over sudden increase in latency for a popular MMORPG in the UK [79]. The problem arose because the game was upgraded to a new version. Network traffic properties of the new game version were changed so much that the traffic management system of the network provider did not correctly label that traffic as (low-latency) gaming class. This resulted in a significantly lower QoS level, and players massively responded by switching to a different network access provider.

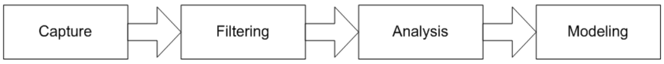


Fig. 1: Typical steps leading to traffic analysis and modeling

Also, game designers can benefit from studying player behavior patterns in designing activities which are more appealing to the players. Game publishers and game providers can use the behavioral information for better design of servers in terms of, e.g., server optimization for minimizing electrical power consumption [44].

2 Network traffic characterization

The volume of game generated network traffic is rapidly increasing. According to Cisco's Visual Networking Index [25], the game traffic is estimated to grow with an annual rate of 37% in the period 2009 – 2014. That represents the second largest growth, after video related categories. While the gaming traffic (still) presents a relatively low overall load on the network, it is the category of traffic requiring the highest QoS. Also, traffic analysis and modeling for networked games are becoming more and more significant, due to the fast growth of the network game market. In order to keep the existing players and attract new ones, game publishers must provide QoS for their virtual worlds (virtual worlds need to be responsive to be realistic). In order to provide the adequate networking service, traffic must be studied, analyzed, and modeled. In this section, we first describe the research methodology applied in the process of traffic modeling. Next, we present the state of the art in the areas of traffic analysis and traffic modeling, followed by the discussion on transport protocol issues for MMORPGs.

2.1 Methodology

To simplify the terminology in this paper, the traffic originating at the client will be referred to as the *client traffic*, while the traffic originating at the server will be referred to as the *server traffic*. To characterize MMORPG network traffic, several typical steps, as shown in Figure 1 are performed: data capture, data filtering, and finally, data analysis and modeling [63]. We now briefly describe each step.

2.1.1 Traffic capture

Traffic capture is a process of recording the network traffic traversing a specific link. The traffic capture can be performed with hardware or software tools (e.g., Wireshark, tcpdump). Data logs created during the traffic capture are usually referred to as "traces". In case of MMORPGs, traffic can be recorded on the communication end-points (client and server) and/or in the network. As opposed to FPS games, MMORPG servers are only hosted by the game providers which makes it impossible for a third party to capture traffic at the server without the consent of and cooperation with the game provider. Hence, most of the measurements found in literature are performed on the client or in the network, but some measurements have also been performed on the server in cooperation with game providers as well [21, 29]. During the traffic capture, especially on the server, it is essential to make sure that the capturing process does not change the characteristics of the traffic. Also, when capturing game traffic, it is very important to take note of the game version, as the MMORPGs constantly evolve and change. In Table 1 datasets of captured network traffic are listed, together with their main characteristics such as dataset size, point of capture, source, etc.

2.1.2 Data filtering

Through a data filtering process, the relevant traffic is extracted from the overall traffic in the trace by identifying the flows between the clients and the server and removing the rest of the packets which are not of interest. While traffic captured on the server may mostly consist of game related data, the traces captured on the client are usually mixed with many non-game related flows.

2.1.3 Traffic analysis

The characteristics of game traffic are determined based on the captured and filtered trace. There are several traffic characteristics which are commonly of interest to researchers:

- *Packet size* (PS) - Packet size is usually presented through the Cumulative Distribution Function (CDF), which describes the probability that a real-valued random variable X with a given probability distribution will be found at a value less than or equal to x. As the MMORPG packet sizes are relatively small in comparison with the TCP/IP header size, often only payload size (i.e., packet size without 40 bytes of the TCP/IP header) is described. Overhead caused by the signaling and its relation to the actual game data transferred is also observed. The usual measurement unit for PS is byte (B).

Table 1: MMORPG traffic datasets

Game	Measurement duration	Measurement point	Dataset size	Source
ShenZhou Online	20 hours	Server	1356 million packets (55 TB)	[19, 21, 22, 24, 84]
World of Legend	7x90 minutes	Client	N/A	[85]
WoW, Lineage II + other non MMORPGs	253 min	Network	526 million packets (382 GB	[33]
Lineage	8 days	Server	3.5 trillion packets	[39]
Lineage II	4 days	Server	12 trillion packets	[38]
Anarchy Online	1 hour	Server	N/A	[32]
Ragnarok Online	206 hours	Client	3 million packets	[23]
WoW, Silkroad Online	9 hours	Client	N/A	[73, 74]
WoW	20 hours + 1 week	Network and client	N/A	[72]
WoW	N/A	Cliet	1.4 million packets	[67, 69, 71]
WoW	N/A	Client	N/A	[81]
WoW	N/A	Client	N/A	[57]
WoW, Silkroad Online	3 days	Client, Network	200 WoW flows, 100 other MMORPG flows	[73, 74]
Legend of Mir	N/A	N/A	N/A	[47]
WoW, Guild Wars, Star Wars Galaxies, EvE	N/A	Client	20k packets	[52]
Second Life	100 hours	Client	N/A	[30]
Second Life	$\sim$ 3 hours	Client	17 million packets	[55]
Second Life	N/A	Client	N/A	[40]
Second Life	8 months	Client	N/A	[13]
Runescape	$\leq$8x1 hours	Client	N/A	[53]

- *Packet rate* - Mean and median values are usually reported. As game traffic rate is usually very variable, burstiness is also often described in order to get the full picture about the packet load. The usual unit for measuring packet rate is the number of packets per second (pps).
- *Bandwidth usage* - Often described with respect to peak values. Unit of measurement for bandwidth usage is usually kilobit per second (kbps) for the client traffic, and megabit per second (Mbps) or gigabit per second (Gbps) for server traffic.
- *Packet inter-arrival time (packet IAT)* - Defined as the difference of the arrival times of two subsequent packets (i.e., the i-th packet and the $(i-1)$-th packet). The term inter-arrival is sometimes replaced with inter-departure times, but in general, this terminology is used regardless of the direction of the packets. Similarly to the packet sizes, this characteristic is often visualized through CDF graphs. Standard unit value for describing IAT is milliseconds (ms).
- *Temporal dependence* - Temporal dependence is defined as the property of a system where the future output is influenced by previous state. In case of network traffic, this translates to whether the previous packet sizes or packet IATs have influence on the following ones. Temporal dependence is usually described through Auto-Correlation Function (ACF).
- *Self-similarity* - Self similarity is usually analyzed for aggregate flows. The level of self-similarity is determined by calculating the Hurst parameter [35].

2.1.4 Traffic modeling

Traffic modeling for games is based on analytic traffic models (i.e., mathematical descriptions). These descriptions can range from very simple ones (e.g., using deterministic values) to very complex ones (e.g., using composition models comprising several distributions). These models are easier both to convey and to analyze than empirical models of traffic (e.g., tcplib [26]).

Modeling of the network traffic of MMORPGs has followed the approach for application traffic modeling pioneered by Paxson [58], and applied in the area of network games by Borella [15]. The modeling procedure is described in detail in [42]. In short, this procedure consists of:

- Choosing an appropriate analytic distribution through inspection of the PDF or CDF of the data;
- Determining the parameters of the distribution through a Maximum Likelihood or a Least Squares estimation;
- If the fit is deviating from the part of the distribution, applying composition modeling (e.g., the upper part of the data is modeled with one distribution and the lower part with another);

– Calculating the λ^2 discrepancy measure [59] (rather than other standard goodness of fit methods, which are biased for large and messy datasets);
– Examining the tail for deviations; and,
– Calculating the autocorrelation function.

Due to its highly erratic distribution, the gaming traffic is very difficult to model properly, even by using a composition of several distributions. A novel method for modeling the network traffic of games is proposed by Shin et al. [65]. A transformational scheme is introduced in order to simplify the shape of the traffic, so it can be mapped to an analytical model. The proposed algorithm is as follows:

– The data is classified into a major dataset and a minor dataset, with respect to a moving average value;
– The minor dataset is used as an input for the next iteration of the process until the proportion of minor datasets is less than a chosen threshold, and
– Major dataset is fully changed into a transformed PDF, and a transform table is generated for the reverse transform in the traffic generation procedure.

In the third step, the non-linear curve fitting is used to obtain an analytical model for each transformed PDF. Through this methodology authors analyze and model packet size and inter-arrival times of WoW and first person shooter game *Left 4 Dead* (L4D) [4] by *Turtle Rock Studios*. Transformational modeling shows better results than traditional modeling for both games. Notably, the packet size of L4D, as the most erratic parameter in these two games, shows almost 10 times better Chi-square statistics for transformation modeling in comparison to composition modeling. It should be noted that authors use Chi-square statistics as opposed to discrepancy. Authors implement their model in a online game traffic generator [64] and show that the generated traffic is following the model in case of L4D traffic, but not for WoW traffic. They further establish the cause of distortions as Nagle's algorithm and Delayed Acknowledgments in TCP. Disabling these options in the generator resulted in adequate goodness of fit levels.

2.2 State of the art in traffic analysis

In this section we focus on the works which analyze network traffic without modeling or inspection of relations between the application state and the network characteristics. Traffic analysis is performed for various reasons such as, e.g., traffic classification, security inspection, network planning, etc. In Table 2 we present which parameters are analyzed in specific studies.

The research group lead by Kuan-Ta Chen has performed very extensive research on traffic patterns of the MMORPG *ShenZhou Online* by *UserJoy Technology Co. Ltd* [9]. They use a 55 TB network traffic trace obtained on the server, with the permission and the assistance of the game operator. They analyze the dataset in several papers [19–22, 24, 84].

An in depth analysis of the gathered trace is performed in [21]. While it might be not the seminal paper in this field, we find it to be a mandatory literature for anyone doing research in the area of network traffic analysis for MMORPGs. The most important findings of the paper are:

– Bandwidth consumption of MMORPGs is very low compared to other action paced games such as FPSs, for example, 7 Kbps for *ShenZhou Online* MMORPG, as compared to 40 Kbps for *Counter Strike* FPS).
– Packet IATs of client traffic conform to exponential distribution with a mean packet rate of 8 pps. Server IATs are more regular. The median value of IAT is about 200 ms.
– Traffic in both directions exhibits short-term temporal dependence within connections. Traffic from the client to the server shows dependence due to the clustering nature of user actions. The same effect in server to client traffic is caused by the spatial locality of the number of characters near the player's character, which shows up in terms of the temporal locality in traffic as the player character moves continuously on the map.
– Temporal dependence exists in the aggregate client traffic. Furthermore, the aggregate traffic in both directions exhibits strong periodicity, which implies synchronized game processing for all clients. Such periodic packet bursts can cause network performance problems.
– Aggregated traffic exhibits self-similarity over a wide range of time scales (for at least 2 hours), which could be explained by the heavy-tailed active/idle periods of individual players.

Also, Chen et al. note that TCP produces a large overhead consisting of 73% of overall client traffic, and find the TCP delayed ACK to be the limiting factor for the Round Trip Time (RTT). The differences between traffic characteristics for active and idle players are found very high, especially in the packet IAT.

Currently the most popular MMORPG with around 10 million subscribers according to MMOData.net [31], is WoW from *Activision Blizzard* [12]. As such, it is a common use case for research involving MMORPGs for both traffic analysis and player behavior. Various aspects of WoW network traffic have been studied, from

Table 2: Characteristics analyzed in various studies on network traffic

Game	Packet size	Packet IAT	Packet rate	Bandwidth usage	Round trip time	Temporal depen- dance	Bursti- ness	Self- similarity	Additional information	Source
ShenZhou Online	+	+	+	+	+	+	+	+	Effect of in game "global events" on aggregated client traffic	[21]
WoW, Lineage II + other non MMORPGs	+	+	+	+	-	-	-	-	IP addresses, used ports, protocol number	[33]
Lineage	+	+	-	+	+	-	-	-	Correlation of bandwidth load and number of players	[39]
Lineage II	+	+	+	+	+	-	-	-	Correlation of bandwidth load and number of players	[38]
Anarchy Online	-	-	+	-	+	-	-	-	Testing different TCP variants	[32]
Ragnarok Online	-	+	+	-	+	+	+	-	Bot identification techniques proposed	[23]
WoW, Silkroad Online	-	-	-	+	-	-	-	-	Analysis of the packet payload	[73, 74]
WoW	+	+	+	+	-	+	-	-	Analyis over five user action categories	[67, 69]
WoW	-	-	-	+	+	-	-	-	Jitter, packet loss, handower impact, measurement in: subway, bus, and stationary, 3 game scenarios: downtown, hunting, battlefield	[81]
Legend of Mir	+	+	-	+	-	-	-	-	Traffic recognition algorithm	[47]
WoW, Guild Wars, Star Wars Galaxies, EVE	+	+	+	+	-	+	-	+	Comparison of different games	[52]
Second Life	+	+	+	+	-	-	-	-	Analysis for actions: standing, walking, flying in popular and unpopular areas	[30]
Second Life	+	+	+	+	+	-	-	-	Analysis of parametrs over separate data channels and classes of user actions: standing, walking, teleporting, and flying	[55]
Second Life	+	+	+	+	-	-	-	-	Analysis of parameters over classes of actions and virtual world surroundings	[40]
Runescape	+	+	-	-	-	-	-	-	Three types of player interaction, network load model	[53]

the security analysis of the traffic regarding login, authentication, and updating the WoW client [34], over inspection of WoW network characteristics for the purposes of traffic classification [33], to models of WoW network traffic [71, 72].

Basic traffic characteristics, such as long-range dependence, and self-similarity of WoW, and another three MMORPGs, namely *Guild Wars* by *ArenaNet* [3], *EVE Online* (EVE) by *CCP* [2], and *Star Wars Galaxies* (SWG) by *Sony Online Entertainment*, have been analyzed by Molnar and Szabó [52]. Statistical self-similarity has been confirmed for WoW, Guild Wars client traffic, and SWG server traffic. In their later research, Szabó et al. focused on the influence of application state on network traffic characteristics [73, 74], which we address later, in Section 4.

In [33], Han and Park present network traffic classification for multiple games, including two MMORPGs: WoW and *Lineage II* [6]. They analyze traffic at the transport layer and propose a classification method called alternative decision tree (ADT). The traffic trace which they analyze has been captured on the border router of a campus network with average utilization of 120 Mbps. Various traffic characteristics are examined, including PS, packet load, bandwidth usage, correlation of packet size distributions between flows of the same application. Their ADT algorithm is based on a simple decision tree with few discriminators. Critical discriminators are PS statistics (i.e., minimum, maximum, mode, mean, distribution), transport behaviors (i.e., mean bytes per second, mean pps) and flow information. For testing the algorithm, they capture 562 million packets with total volume of 282 GB on which they show that their algorithm has high precision and recall.

A different type of recognition algorithm for the network traffic of a single MMORPG *Legend of Mir* by *Wemade Entertainment* is presented by Liu, Yan, and Zhou in [47]. They use traffic recognition based on payload inspection in order to extract the MMORPG traffic from the traffic mix. They describe basic characteristics of the traffic, such as PS and packet IAT CDFs, bandwidth usage, and ratio of packets carrying game information to pure signaling packets.

The Lineage saga – including *Lineage* and *Lineage II* – by *NCsoft* [5,6] achieved a huge market success in Korea and Taiwan. Traffic characteristics of both MMORPGs have been investigated by Kim et al. [38, 39], the research group from the Seoul National University. Their work is particularly interesting as it provides insight into how game traffic has evolved from first release of the game to the sequel.

In [39] the traces captured on the server of *Lineage* are analyzed. Authors have captured over 281 GB of data over 8 days. Client packet sizes are very small and narrowly distributed while client packet IATs were between 0 and 20 seconds with an average value of 386 milliseconds. Server packet sizes have a wider distribution while packet IATs are similar to client traffic with average value of 438 milliseconds and 99% of packets departed within 4 milliseconds. Also, authors look into average connection time per flow (49.68 minutes), and show that bandwidth consumption during the week has an evident daily pattern which authors explain through linear correlation between number of users and bandwidth.

The sequel, *Lineage II*, is analysed in [38]. Again, the traces are captured on the server with the assistance of the MMORPG operator and around 7.7 billion data packets have been captured. It is shown that the major characteristic of the MMORPG traffic is an asymmetry of upstream and downstream traffic. They note that the client traffic contains 22.9% data packets while the server traffic contains 97.6% data packets. Comparing this game with its prequel *Lineage*, authors note a significant increase in the size server packets (around 15 times larger). Although this result is not generic, nor conclusive, it suggests that the MMORPG traffic may tend to become more demanding as the genre evolves. Authors confirm there is a linear correlation between the number of active users and the client traffic (correlation coefficient 0.99), as well as the server traffic (correlation coefficient 0.95). The deviation of the correlation of the server traffic and the number of players is explained by APDU segmentations (segments larger than MSS), which incurs additional TCP/IP overhead. Average IAT of packets within session is around 200 ms due to the TCP delayed ACK system. Authors suggest that delayed ACK system should be changed in order to reduce the Round Trip Time (RTT). Also, a strong correlation between number of users and aggregated upstream and downstream traffic has been found. As for the distribution of session durations, significant heavy tailed characteristics have been found (e.g., the longest session duration measured is 80 hours). Session IATs show an average value of 401 milliseconds, while at peak times (on average) 2.5 new users arrive every second.

Chen, Jiang, Huang et al. [23] analyze the traffic of the game *Ragnarok Online* [7] by *Gravity*, in order to identify game bots (i.e., automatically playing game clients). They gather over 3 million packets in 206 hours through the client measurements. The traffic has been captured during the gameplay involving four real players and two bot programs on different networks. The analysis shows that IATs for packets belonging to bot traffic show significant differences to that of the real (human) players, due to timers. They calculate the entropy of each trace in order to describe the degree of randomness of packet IATs and confirm that players have higher entropy than bots. Also, they provide a suggestion for a threshold which distinguishes the players from bots, but indicate that the entropy depends on the segment size. They also look into the client response time (i.e., difference between a client packet's departure time and the most recent server packets inter-arrival time) and burstiness of the traffic. Based on noted traffic characteristics, authors propose four general decision strategies and two integrated schemes for bot detection.

To summarize this section, the traffic characteristics of MMORPGs are indeed well studied. The streams are very "thin", with a rather low packet rate, but with a larger packet size than in FPS games. There is significant asymmetry between the client traffic and the server traffic. Some MMORPGs generate traffic with self-similar properties. As the genre evolves, it is likely that the corresponding traffic requirements will increase, as shown by comparison between *Lineage* and *Lineage II*.

2.3 State of the art in traffic modeling

In this section we present only the basic models which describe the statistical properties of the observed network traffic. The more complex models which take into account state of the application are presented in Section 4.

Svoboda, Karner, and Rupp [72] analyze the traffic trace captured within a 3G mobile core network

Table 3: Statistical distributions applied in traffic models

Game	Packet size		Packet IAT		Source
	Client	Server	Client	Server	
World of Legend	deterministic	2 deterministic + Extreme Value	Extreme Value	Sum of two Extreme Value	[85]
Lineage	N/A	Power Lognormal	N/A	Extreme Value	[39]
WoW	3 deterministic + Generalized Extreme	N/A	2 deterministic + Normal	N/A	[65]
WoW	deterministic	Weibull	Joint distribution of 3 random variables	Joint distribution of 3 random variables	[72]

and note that the significant part of traffic is coming through port TCP:3724, a well-known port for WoW. They establish that WoW is among top 10 TCP based services in the monitored network and that it constitutes 1% of all TCP based traffic. Also, they perform measurements and capture a trace of two groups consisting of five WoW clients connected to an ADSL line. Analysis at packet level shows that the packet size in the downlink direction is quite smooth and can be modeled with a Weibull distribution, while the uplink packet sizes have large discrete steps. They note that the high number of transmitted packets are ACK packets carrying no application data. Inter-arrival time was modeled by a joint distribution of three variables. Authors state that the modeled traffic conforms well to the original traffic in terms of the bandwidth CDF, but that the original burstiness of the traffic was not captured well.

Shin et al. compare their transformational modeling procedures to standard modeling techniques [65]. To model the traffic of WoW through standard techniques, they use a complex mixture modeling in order to prove that their approach can provide better results than very complex models.

Wu, Huang, and Zhang model the traffic of a one of the most popular MMORPGs in China – *World of Legend* [11] from *Shanda corporation* [85]. Their model is based on a trace obtained on a client accessing the game through a mobile GPRS access network. The trace consists of 7 traces of 90 minutes each.

Previously described work by Kim et al. [39] also presents the traffic models of *Lineage*. It should be noted that the authors do not state whether their models are for the client, the server, or the aggregated traffic (we assume it is for server traffic, based on its characteristics).

Distributions used for the listed models are summarized in Table 3. Client packet sizes have deterministic values, while other aspects of the traffic are modeled with continuous distributions.

2.4 Transport protocol issues for MMORPGs

As MMORPGs are complex applications which, depending on the situation, require timely delivery of data packets and/or reliable packet delivery, there is an ongoing discussion about the suitability of current transport protocols for MMORPGs. Also, there are some research efforts aimed at the design of new protocols suited for MMORPGs, which we describe later in this section.

Using the same 55 TB trace evaluated in [21], Chen et al. evaluate the TCP performance for MMORPGs [19]. They try to find out which transport protocol should be used for online games: TCP, UDP, or some other protocol. Based on the characteristics of the traffic such as: tiny packets, low packet rate, application-limited traffic generation, and bidirectional traffic, they claim that TCP is not a suitable protocol for MMORPGs. As TCP was originally designed for network-limited bulk data transfers, it does not adapt well to the requirements of MMORPGs. For instance, the TCP's fast retransmit mechanism is highly ineffective, as only 0.8% of all dropped packets are detected by the fast retransmit mechanism. As the packet rate is slow in MMORPGs and the packet inter-sending time can be longer than the retransmission timeout (RTO), TCP assumes that connection is idle and unnecessarily resets the size of the congestion window. Tiny packets that MMORPGs send also cause a high signaling overhead (46% of the overall bandwidth used). In the end, the authors present the following guidelines for designing a more efficient protocol for online games:

- Support for both reliable and unreliable delivery
- Support for both in-order and out-of-order delivery
- Accumulative delivery
- Multiple streams
- Coordinated congestion control

In further analysis of the trace, the authors provide the basic guidelines for a design of a transport protocol for MMORPGs [84]. They design the following transporting options: *multi-streaming* which enables separate streams for different types of game messages;

optional ordering which allows certain messages to be processed as soon as they are received without being buffered if the preceding messages have not yet arrived; *optional reliability* - the messages which do not require reliable transmission and can be ignored. In order to compare their new approach with existing transport protocols (TCP, UDP, DCCP, and SCTP), they conduct network simulations with a real-life game trace from the game *Angel's Love*. The comparison shows that the proposed strategies can effectively raise the level of game satisfaction among players through significantly reducing end-to-end delay and jitter. The main problem is that it is necessary to identify game packets according to the type of content.

Griwodz and Halorsen [32] analyze a 1-hour long network trace of an MMORPG *Anarchy Online* [1] made available to them by the game provider *Funcom*. They show that while single TCP streams are thin, the server link can be carrying hundreds or thousands of concurrent streams which together may cause congestion without reducing the sending rate. Authors claim that using TCP does not have to be slower than using UDP, as the send buffer is usually empty and an event may be sent immediately. Repeated timeouts ruin the game experience because the number of in-flight packets is so small that fast retransmission due to multiple duplicate acknowledgments is very rare. They tested multiple TCP implementations and found little effect on the performance of a MMORPG, but were able to get better results with modifying Linux kernel with a new calculation for the value of the retransmission timeout (RTO). The QoS gain from this method has been shown to be significant when there is need for a higher number of retransmissions (i.e., the lag experienced by the player due to repeated packet loss is reduced). Authors suggest introducing a proxy server as many clients share a network path in order to reduce the load on the server up to 40% and reduce maximal and overall latency to the clients (due to a lower loss and fewer retransmission, as introducing proxies always causes the increase of latency).

To summarize, it is evident that the current transport protocols (TCP, UDP, DCCP, and SCTP) are not particularly suitable for MMORPGs, due to the characteristics of game traffic. The TCP mechanisms such as delayed acknowledgment and Nagle's algorithm deteriorate the performance of MMORPGs, as does the TCP's congestion control mechanism. The design of a new transport protocol for MMORPGs is still an open research issue. Reliable, in-order packet delivery over UDP has been designed by *ENet* for an FPS [10], but to the best of our knowledge there are no studies regarding ENet's performance for MMORPGs.

3 Player behavior and session characteristics

Understanding player behavior is essential for several key aspects of the MMORPGs such as planning and developing better architectures for virtual worlds, predicting game life-span and players disinterest in the game, scalability solutions in order to avoid server saturation leading to heavy degradation of QoS and even unavailability of the certain areas of the virtual world. In this section we present the current research efforts regarding session characteristics.

3.1 Measurement methodology and characteristics

In this section we describe behavioral datasets obtained through various measurement procedures, found in literature. The datasets are grouped according to the method by which they were obtained. Four methods for measuring player behavior have been identified, as follows: 1) extracting the behavioral data from the network trace, 2) polling measurements from the client by using game mechanisms, 3) proprietary logs obtained in cooperation with the game operator, and 4) measurements on players' computers.

In Table 4 we present the datasets we are aware of, with key information, such as type of the measurement, duration, dataset size, etc. We find these datasets to be of top importance to new researchers in the field, allowing them to avoid long and demanding measurement procedures, and be able to perform own analysis and validate models on existing datasets.

We start by listing and explaining the most relevant player behavior and session related characteristics, namely, the session duration, the number of active players, the spatial distribution of players in the virtual world, the movement of players, and the long term analysis. We summarize which characteristics are studied in which reference(s) in Table 5.

3.1.1 Session duration

In MMORPGs, a session may be loosely defined as a period of time devoted to gaming activity. A session duration (length) is usually defined in one of the two different ways: 1) as a time interval between log in and log out of a specific character, and 2) as a total time spent playing, i.e., the time interval between starting a game and exiting from it. For the purposes of this paper, we refer to these types of session as the "character session" and the "player session", respectively. For character sessions, the session length can be measured based on character's availability in the virtual world. A number of authors have measured this type of session

Table 4: MMORPG player behavior datasets

Game	Measurements duration	Measurements point	Dataset size	Dataset type	Source
ShenZhou Online	20 hours	Server	1356 million packets (55 TB)	Network traffic trace	[20–22, 24]
EVE Online	∼ 3 years	Server	67060901 sessions	Session log	[29]
WoW	∼ 5 weeks	Client	∼3300 snapshots of active players	Player log	[61]
WoW, Warhammer Online	4 months (WoW), 2 weeks (WaR)	Client	115000 players and 75000 session with tracked movement	Player log	[60]
WoW	5 months	Client	∼20500 snapshots of active players, ∼15000 snapshots of locations	Player log, location log	[87]
WoW	664 days	Client	∼95500 snapshots of active players	Player log	[75]
WoW	273 days	Client	∼39000 snapshots of active players	Player log	[44]
WoW	1107 days	Client	138084 snapshots of active players	Player log	[45]
WoW	20 hours + 1 week	Client and Network	1000 players observed	Network traffic trace	[72]
WoW	1.5 months	Client	2753 character sessions	Player activity log	[67]
WoW	1.5 months	Client	11775 character sessions (5872 player sessions)	Player activity log	[66]
WoW	N/A	Client	129372 observed players	Player log	[28]
EverQuest II	8 months	Server	N/A	Timestamps of task completion, quests played, points received by the users	[36]
Rockymud	12 months	Server	556 avatars	Timestamps of user log-on, log-out, and movement	[41]
Second Life	1 day	Client	∼165000 avatars	Network traffic trace	[46]
Runescape	6 months	Client	11000 data samples of server load	Snapshots of number of players for each server group	[53]
Second Life	28 days	Client	17573 covered regions	Crawler log	[77, 78]

length [44, 45, 75, 87]. Those measurements usually use a script, commonly called an *add-on*, which runs within the MMORPG client, and enables the client to poll all active characters in the virtual world. In this manner, data can be gathered with relative ease, as the only thing needed for this measurements is one computer running the game and the said script.

For player sessions, it should be noted that a player can have and use multiple characters, so the player and character session lengths are not the same. A player usually has one "main character" and several "alternative characters", commonly referred to as "alts". As one player session typically comprises several character sessions, measurement results describing player sessions differ from those describing character sessions. Player sessions may be measured in two ways, either by capturing the network traffic and extracting the data about the player sessions from the trace [37, 72], or, by measuring the session length by deploying add-ons on players' computers [66].

Due to lack of uniform session definition and the diversity of measuring techniques, reports on session length measurements found in literature tend to differ significantly, even for the same game. Figure 2 clearly illustrates this by showing the reported session length results referring to the same game (i.e., WoW). The shortest overall session duration is reported in [67], by measuring character session length with 1 minute pre-

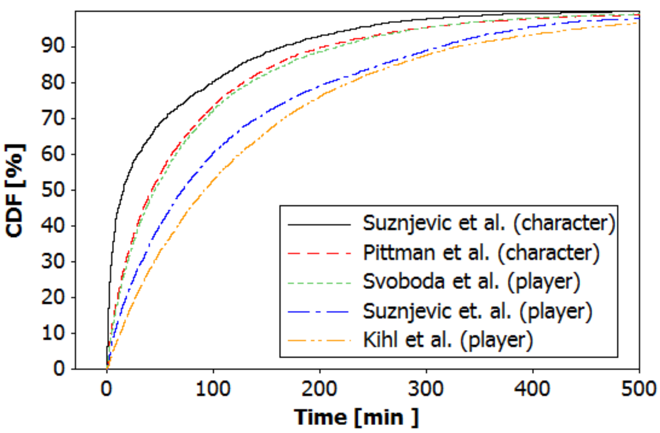


Fig. 2: Differences in session length distributions for character sessions and player sessions

Table 5: Session duration and player behavior characteristics in various studies of player behavior

Game	Session duration	Player load	Spatial distribution	Player movement	Long term analysis	Additional parameters	Source
ShenZhou Online	Player	-	+	-	-	Duration of map sessions, IATs of game and map sessions	[20–22, 24]
EVE Online	Character	+	-	-	+	Impact of updates on player growth and amount of time spent playing	[29]
WoW	Character	+	+	+	-	Identifying four facets for a complete behavioral model	[61]
WoW, Warhammer Online	Character	+	+	+	+	Behavioral model – session length: Weibull, player distribution (per zone): Weibull, movement: linear equations, time in zones: Weibull	[60]
WoW	Character	+	-	-	-	Player load observed in the 3 zone types: questing, transit, and city, availability, OFF period analysis	[87]
WoW	Character	+	-	-	+	Prediction of long term behavior, ON and OFF periods analysis	[75]
WoW	-	+	-	-	-	Server zone based consolidation strategy proposed	[44]
WoW	Character	+	-	-	-	Daily session count, daily play time	[45]
WoW	Player	-	-	-	-	Session length:Weibull	[72]
WoW	Character	-	-	-	-	Definition of user action categories, session composition, action specific segment duration	[67]
WoW	Player	-	-	-	-	Measuring of written and voice communication in game	[66]
EverQuest II	Character	-	-	-	+	Algorithm for player churn prediction	[36]
Rockymud	Player	+	+	+	-	User behavior model, session IAT	[41]
Second Life	-	+	+	+	-	Arrival and departure rates, meeting characteristics	[46]
Second Life	-	+	+	+	-	Meeting characteristics, regional analysis , user generated objects	[77,78]
Runescape	-	+	-	-	-	Regional analysis, three types of player interaction	[53]

cision (30% of the sessions reported were shorter than 5 minutes). Character session lengths are also reported in [60], using a 15-minute sample time, while in [72] player sessions are examined, based on a traffic trace captured in a mobile 3G network, in which sessions in general tend to be shorter than in wired networks. In [66] player sessions with 1-second measurement precision and additional parsing to ignore disconnecting are reported. Player session length based on the results of traffic measurements in a wired access network are reported in [37].

3.1.2 Number of active players

The number of active players in a virtual world (i.e., player load) of a MMORPG can vary significantly based on the time of the day and the day of the week. Server's computational load and the network load (in terms of number of packets per second and bandwidth usage) depend very much on the number of active players. Depending on the architecture of the virtual world, the number of players may vary. In "sharded" systems, in which the virtual world is replicated on multiple shards and the players on a specific shard can not interact with the players on other shards (e.g., WoW)), the number of active players is typically in the range of several thousand. On single shard systems (e.g., EVE Online), all players are located in one virtual world and the number of players is measured in tens of thousands. Player load patterns are usually reported for a specified time frame, for example, hourly, weekly, monthly and yearly. Hourly patterns are usually observed to analyze the number of players over the 24 hours in the day, daily patterns to capture the trends with respect to day of the week, and so on. As shown in Figure 3, created by using the data extracted from the dataset by Lee et al. [45], in addition to having a prominent hourly pattern, also displays a daily pattern. Two groups may be observed, weekdays and weekend. Weekdays have a very similar number of users playing on all days except Thursdays (which appears to be the weekly maintenance day on the monitored server). Maintenance day means that virtual world goes off-line, which means there are no active players in that period. Saturdays and Sundays have significantly many more players, especially during the day, which is expected based on, in general, higher availability of an average player during the weekend.

3.1.3 Spatial distribution of players in the virtual world

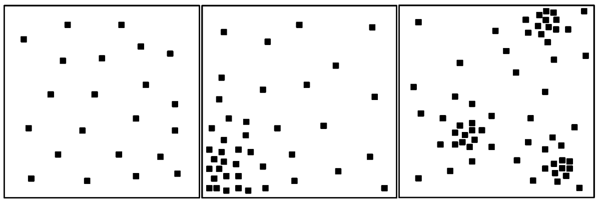
Virtual worlds of MMORPGs can be very large in terms of virtual space (e.g., estimated size of virtual world of WoW is around 100 square kilometers without virtual space added in expansion packs [80], while *Lord of the Rings Online* is estimated to have 50 square kilometers of virtual space [48]). Thus, it is very important to understand the spatial distribution of the users in order to assign a corresponding amount of computational power for specific parts of the virtual world. Examples of avatar's spatial distribution in the virtual world are shown in Figure 4. Pittman and GauthierDickey have established that players are not uniformly distributed within the virtual world [61], but that there are "hot spots" in which there are many concurrent players, while in other parts the virtual world can be almost "deserted".

3.1.4 Movement of players

Movement of the players in the virtual world is often characterized by the number of visited zones in one session, and the time a character has spent in a specific zone [60]. Zones are geographical partitions of the virtual world which are processed by separate servers or server resources. Miller and Crowcroft focus on smaller scale and model the player movement patterns in a specific zone [51], [50]. Player movement information matters for evaluating geometric routing schemes, some P2P architecture performance is heavily dependent on player distribution, dynamics, and density of the avatars [14,76].

3.1.5 Long term analysis

By long term analysis we mean tracking players for a longer period of time, like months and years, in order to examine and predict subscription dynamics. Long term analysis of player behavior is a key to understanding and estimating player churn (i.e., when will a player stop playing the game). Such analysis typically requires access to game provider's logs.



(a) Uniform (b) One hot spot (c) Many hot spots

Fig. 4: Types of avatar spatial distribution

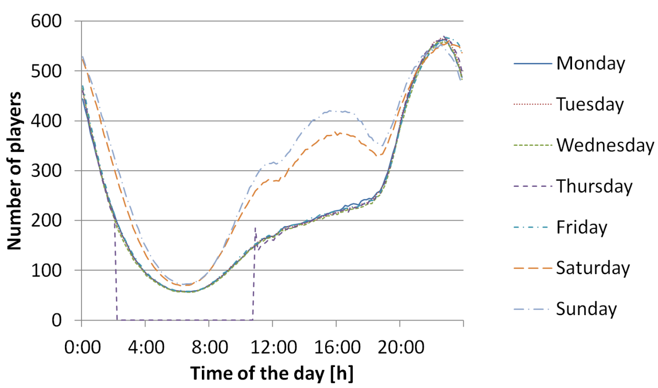


Fig. 3: Number of active players across days of the week extracted from dataset by Lee et al. [45]

3.2 Behavior analysis based on network traffic traces

In this section we present the results regarding player behavior extracted from network traffic traces. By inspecting network traffic it is possible to identify player load, player session length, impact of network characteristics on players' behavior, etc. The downside of this approach is that it is difficult to identify specific players and their return to the service which makes player specific analysis complicated.

Session characteristics of the ShenZhou Online have been extracted from a 55 TB network traffic trace captured at the server, and reported in a number of papers [21,22,24]. In [21] authors, apart from the previously described very detailed traffic analysis, examine two types of sessions: (1) map session which is defined as the time period in which the character stays within a particular map area; and (2) game session which is defined as the period in which a player remains in the game. Game session duration is heavy tailed and session arrival process can be modeled as a *homogeneous Poisson process* (HPP) within 1-hour intervals. Time of day has significant impact on session inter-arrival times. On the other hand, map session arrivals can not be modeled as such, which is, according to authors, an effect of the team play – as players tend to cross the boundaries of the maps together. Regarding player behavior, authors state that clustering nature of player actions (i.e., issuing commands from the players tends to be successive and in bursts) have major impact on the ACF function of the packet IATs. Furthermore, authors state that the diversity of user behavior makes it difficult to define a "typical player", which makes modeling user behavior and source traffic of MMORPGs especially challenging. Chen et al. examine the relationship between network

QoS and session times using the survival analysis [22]. They determine that both the network delay and the network loss significantly affect players' willingness to continue the game (or not). Also, they have determined that delay jitter is more important than absolute delay in terms of playing time. Quantitatively they have determined the degree of player intolerance to the minimum RTT, RTT jitter, client loss rate, and server loss rate, to be in the proportion of 1:2:11:6. Specifically, a player's decision to leave a game due to unfavorable network conditions is based on the following levels of intolerance: minimum RTT 5%, RTT jitter 10%, client packet loss 55%, server packet loss 30%. In [20] Chen, Huang, and Lei test whether network game players are as sensitive to the network quality as they claim to be (often complaining about high "ping times" or "lags"). They confirm the relationship between network QoS and the game playing time which could serve as a measure of satisfaction of the players.

While this survey is focused on MMORPGs, we also present a few studies that focus on online collaborative virtual environments (CVEs). We take *Second Life* (SL) by *Linden Labs* [8] as an example because it is currently one of the most popular social 3D virtual worlds. It should be noted, however, that CVEs and MMORPGs differ significantly, in that in CVEs there are no game mechanics, rules, and predefined goals as in games, and the focus is on the community and content creation. The concept of SL is that players can explore, interact, and – most importantly – change the content of the virtual world. The fact that players can add new 3D objects into the virtual world has major impact on the way the world functions, and naturally, on the network traffic generated. As shown in Figure 5, the traffic demands of SL are far higher than for MMORPGs, as well as other game types. Data for this figure has been extracted from [40] for Warcraft III (RTS), Madden NFL (Sports), Unreal Tournament (FPS), and from [72]) for WoW. Due to the higher network demands, it is especially interesting to see the impact of player behavior on network characteristics in SL.

Liang et al. [46] study the behavior of users in SL. Their trace comprises the network traffic captured on a client running a bot for SL, which visited the designated areas of the virtual world. Information about other avatars in the region visited by the bot can be obtained by parsing the network traffic trace (i.e., from server side updates). The authors note that islands in the SL virtual world have variable numbers of avatars present. They examine session behavior (population over time, arrivals and departures, stay time, and returning to same island), mobility of users (number of visits, average speed in a cell, and average pause time), and

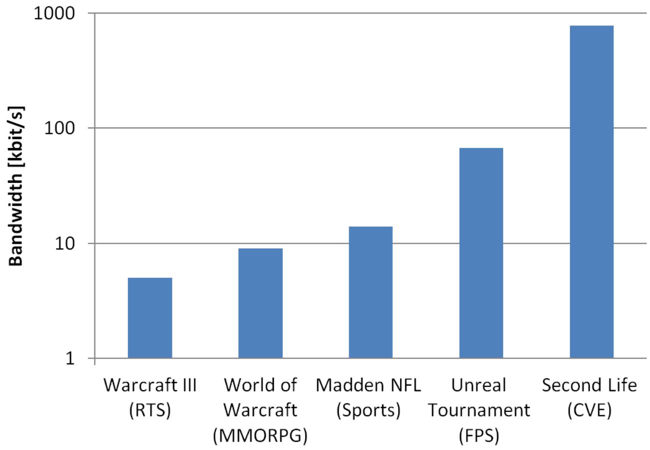


Fig. 5: Bandwidth usage of games of different genres

contact patterns (meeting duration, meeting stability, and average meeting size). They suggest new mobility models, and improvements for load balancing and zone partitioning.

3.3 Analysis of game provider's logs

The analysis of game provider's logs can yield the most reliable and in-depth results, provided there is a cooperation between the researchers and the game providers. Long term analysis can provide valuable results to game providers, as it can be used to estimate and/or predict player churn and find its causes. Stopping or slowing churn has a direct impact on the game provider's revenue. This is why most studies of game provider's logs include some aspects of long term analysis.

Feng, Brandt and Saha [29] have performed a long term study of a popular space combat MMORPG EVE Online on a complete session log of EVE since its launch. Their aim has been to determine whether (and how) the MMORPG workload and individual players are predictable. The measurements, taken over a 3-years' time, show a significant increase of concurrent player population in EVE. Authors discover that workload displays significant hourly and daily patterns, with regular hourly and daily peaks. Observation of a player joining and quitting the game has shown that joining and quitting are highly correlated, meaning that most of the players try the game for a short while before quitting, as the game does not interest them enough to play for a longer period. Player churn increases strongly as the game is maturing, meaning that new players joining are much more likely to stop playing. Also, by examining session times authors prove that there are ways to determine whether the player would soon quit the game by examining intersession times.

Kawale, Pal and Srivastava [36] analyze the dataset of the MMORPG *EverQuestII* (EQ2) provided by the game publisher *Sony Online Corporation*. The dataset consists of "complete experience data" of all players over an 8-month period, from January to August 2006. Specifically, it comprises data regarding when users completed a task, quest, and received points, so information on which players played together can be extracted. Also, the dataset contains the list of all EQ2 players that unsubscribed in months August, September, and October. Authors aim to predict the churn, i.e. the number of players who would leave the game, based on player engagement estimation, which they evaluate using session length and session time. They evaluate three models for predicting player churn: 1) simple diffusion model, 2) classification based on network and player engagement, and 3) modified diffusion model. Results suggest that modified diffusion model for the social influence on the player, which takes into account player engagement, based on activity patters performs the best.

Kwok and Yeung [41] model the user behavior of *Rockymud*, based on the measurements taken during 12 months. Rockymud is a game in which avatars can change location between rooms comprising the virtual world (it comprises 10,000 rooms). User behavior is described through several parameters: probabilities of moving between specific rooms (modeled as a Markov chain), residence time in rooms (modeled by Pearson distribution with various parameters for different rooms), IAT between arrival of new users (modeled by exponential distribution), and session length (modeled by Pareto distribution).

3.4 Analysis based on client polling

The principle behind client polling measurement is to use application specific capabilities of clients in order to obtain more information regarding the state of the virtual world. In WoW, this method is based on using the */who* command through the WoW interface, which returns the list of players currently online with some additional information (e.g., zone in the virtual world the players are currently in, level of the players, etc.). This is a very easy and non intrusive way for collecting a relatively large amount of player behavior data and it is often applied in a number of research publications which we briefly describe here.

Pittman and GauthierDickey [61] study virtual populations and their behaviors in WoW over a time period of 5 weeks. The polling is performed every 15 minutes. Four facets needed for a complete player behavior model are identified: 1) population changes over time, 2) arrival rates and session duration of players, 3) spatial distribution of players over the virtual world, and 4) movements of players over time. They confirm the existence of the hourly and also daily patterns of the number of concurrent users. The difference in the number of players in a daily pattern is shown to be almost five-fold. As for the session lengths, they confirm that most of the sessions are very short lived: 50% of the sessions were less than 10 minutes long, while 90% of the sessions were less than 200 minutes long. The spatial distribution of players in the virtual world proves to be following a power-law distribution, with most of the players visiting six or fewer zones, and 40% of the players staying within only one zone. Artificial workloads using uniform distribution of the players differ significantly from the situation which is observed in their measurements. In their following work [60], they develop behavior models for WoW and *Warhammer Online* (WaR) by *Mythic Entertainment* [83]. In that work, they prove that two MMORPGs with different play styles can be modeled by using a unified set of functions. The modeling is based on traces gathered for 4 months for WoW and for 2 weeks for WaR. The dataset comprises 75,000 sessions in which movement was tracked, and 115,000 individual characters. Their full behavioral model consists of modeling session lengths (Weibull distribution), player distribution through zones (Weibull distribution), number of zones visited related to session lengths (linear dependence), time spent in zones (Weibull distribution), and player movement (Log-normal distribution).

Zhuang et al. [87] perform an extensive study of WoW by monitoring the behavior of over 1000 players over a course of 5 months. The frequency of polling used is once every 5 minutes. Regarding the player count, they determine an existence of an hourly pattern, but they do not find that there is a significantly higher number of players that enter the virtual world on weekends than on weekdays. Authors determine a median of 50 minutes for the session length, with the longest session lasting around 12 hours. Longer sessions begin in the evening and the night, while much shorter sessions begin in the morning. Downtime shows a daily pattern, and median of 179.38 minutes, which is remarkable, because of the human daily behavior patterns such as sleep and work. Measurements show that average player availability is around 2%, which equals to 30 minutes per day. Players are highly independent, with majority of the players "going solo", or in pairs. Authors partition the virtual world zones into 3 types: *Questing*, *Traveling*, and *Cities*. As far as differences in specific zones are concerned, questing zones show the highest average “staytime” (i.e., amount of time player spends in one zone), followed by cities, and then by traveling zones. The density of players is highly variable, as main cities have the greatest density, while questing areas have a far lower one. Also, density changes over time (i.e., newly added content typically attracts a large number of players).

Tarng, Chen, and Huang [75] analyze WoW player's game hours, on a trace sample gathered for almost two years. This dataset is the result of polling performed every 10 minutes. While authors talk about 34521 accounts observed, it should be noted that they are examining characters (i.e., one user account can have more than one character). Subscription time is modeled by using a survival function rather than estimating it through cumulative distribution function since players' subscription times are censored (spanning out of the time line of the measurements). They conclude that the game is very addictive, as 60% of the users are still observed one year after their first visit, while 50% of the users subscribe for longer than 500 days. They also analyze ON and OFF periods. The ON periods are defined as days in which a player logs into the game at least once, and the OFF periods are defined as the days in which a player does not log in. Authors note that the ON and OFF periods for around 80% of players are shorter than 5 days. A strong pattern in the number of active players is noted for the hours of the day. Also, a daily trend in player login count has been noted, but not as strong as the hourly trend. Additionally, authors try to predict player long term behavior based on their short term behavior. Short term behavior is described based on average session time, average daily session count, and average daily playtime.

Lee and Chen [44] use the same strategy for gathering the trace on which they study the hourly, daily, and weekly patterns of player numbers based on measurements from “alliance” faction on WoW server in Taiwan - “Light's Hope”. They propose a zone-based server consolidation strategy which uses the number of players and spatial locality to lower the hardware requirements and energy usage. To evaluate the proposed consolidation strategy, they have performed simulations which indicate that using a dynamic hourly based policy can significantly reduce the number of required servers (i.e., around 50%), as well as the energy consumed for both the single-game and the multiple games scenarios. In their following work, Lee and Chen present a large dataset [45] comprising measurements taken in a 1107-day period between January 2006 and January 2009, using an add-on which runs the */who* command every 10 minutes on the same server in Taiwan, but on the other in-game faction – “horde”. The dataset includes the avatar's game play times and a number of attributes, such as their race, profession, current level, and in-game locations. Authors examine the patterns of player load for hours of the day, days of the week, week in the month, and monthly patterns. Strongest patterns are evident for hours in a day and daily patterns in avatar numbers are also evident (more players on weekends). Weekly and monthly differences are not that strong.

A study by Ducheneaut et al. [28] differs significantly from previous studies. Authors focus on the social aspect of a MMORPG and measure player behavior in WoW through several very specific parameters such as the time spent per level, group ratio per class, percentage of time spent in group with other players, guild membership, and loyalty. They have found out that the time required to reach a certain game level rises slowly but very regularly, which indicates that WoW is a balanced game in which the difficulty increases gradually with the possibility of progress always within reach. Players tend to choose the classes (i.e., types of characters, with specific abilities and roles) that are most “soloable”, or, in other words, able to perform well on their own. Time spent in group per class indicates that players play alone if they can. Also, players who spend less time in groups gain levels faster than the players who are frequently grouped. Results show that the players' grouping time increases as they reach the level limit, as they come to the part of the game where most of the content is too hard to complete as one person, meaning that the endgame is social, but not the game as a whole. Regarding guilds (i.e., player associations in game), it has been shown that players within a guild spent more time playing than those out of the guild, which confirms the hypothesis about social pressure. Analysis of the guild structure showed that they are, in general, fairly small, with 35 members on average, and that most guilds contain a small core of people who tend to play together, while the rest of the guild is not so closely tied. This phenomenon has been recognized by the game publisher, which has systematically over the course of the game reduced the requirements for group actions. The most challenging and rewarding group based activities in the game, so called “raids” have at first been designed for 40 people, while the first game expansion reduced this requirement to 25 people, and in the next expansion further down to 10 people. Authors continue their work on studying the social behavior in MMORPGs with the emphasis on guilds [27]. They examine their structural properties such as size, demographics based on level, strength of the relationship between guild members, and guild evolution through time. Results show that, in general, the guild churn is very high, and that a guild life time is short, but also that guilds with balanced class composition and more active players tend to survive longer. Authors have also developed a social dashboard tool in order to visualize and explore guild survival metrics.

A similar concept is used in another set of studies of SL performed by Varvello et al. [77, 78]. The authors have designed several "crawlers", based on a modified client application which uses the capabilities of an avatar to gather information regarding the virtual world. These crawlers travel the SL virtual world autonomously and collect information about the statistics of the virtual world, evolution of user created object, positions of players on a map, etc. Through this technique a very high level of detail information is obtained. Authors report some very specific statistics such as region popularity, group popularity, object distribution and dynamics etc. Additionally, authors investigate Quality of Experience of SL users and find that it is rather poor and that there are significant inconsistencies between the states of the virtual world which are displayed to different users (e.g., one dynamic object can be displayed in different locations for different users).

3.5 Analysis based on measurements on players computers

Measurement on players' computers for gathering player information is based on add-ons for a MMORPG client. The players participating in the measurement need to agree to install the add-on and submit (usually at least partially anonymized) behavioral information. This approach is opposite from the concept of polling add-ons, which are deployed to be used on only one account which monitors all active characters. The ability to observe the player behavior in more detail, acts both as an advantage and as a disadvantage of this approach, since it is rather difficult to find players willing to participate in such research. Suznjevic, Dobrijevic, and Matijasevic apply this approach in [67] to classify the user behavior. They propose five player action categories focusing on player progression in the game (*Trading, Questing, PvP Combat, Dungeons* and *Raiding*). Six players have participated in the study over a one and a half month period, resulting in 2753 recorded player sessions. Authors measure session length, but also the percentage of time spent playing in each category during the time where a pattern in user behavior is evident. Segments of the session comprising only one action category are also measured, and it is noted that the Raiding category has the longest sessions. In the following work [66], authors measure the behavior of 104 players over one month and a half. In addition to monitoring of player behavior in terms of previously defined action categories, authors also assess players' written communication, as well as use of Voice over IP (VoIP) communication during the game. A strong trend is observed for the hours of the day, especially for the Raiding category which is dominantly performed in the evening. A pattern is observed also in the days of the week, where Raiding is significantly less present on Fridays and Saturdays. Communication is stated to be very important to the players as players are communicating 17% of their active play time, and voice communication is used by 94% of the players. An in-depth study of using voice communication during gameplay is presented by Papp and GauthierDickey in [56]. Authors study characteristics of voice communication on a TeamSpeak server. A total of 7,749 sessions is captured and the duration of the talk spurts and silence periods is reported.

Suznjevic and Matijasevic [68] further examine the behavior of players and link it to psychological motivators for MMORPGs defined by [86]. They find that players strongly motivated by *Teamwork* motivational component have increased time played in Raiding, and that motivational component *Relationship* has a positive influence on how much players communicate while gaming.

Finally, they present the model of player behavior based on the gathered information and implement it in a player behavior simulator [70]. The model comprises several components: 1) the first order Markov chain which describes the probabilities of switching between action categories during the session, 2) homogeneous Poisson processes describing the arrivals and departures of players on one server for one hour, and, 3) models of session lengths and action specific session segment lengths. The authors have also captured hourly and daily patterns through different parameters for different times of day and days of the week.

The research regarding the player behavior has been approached from several standpoints and by using various measurement techniques. When using the results of previous works one must be aware of the advantages and limitations of each technique. Also, results regarding some well studied parameters such as session duration, need to be taken with full understanding of what is measured and how. Player behavior analysis and models are vital tools for dynamic resource allocation, which can bring significant cost reductions to game providers. While there are works regarding churn mechanism, there is a lack of more in depth analysis of player behavior and what types of behavior can be linked to players disinterest and finally, quitting the game.

4 Influence of virtual world state to network traffic

The parameters of the of the virtual world state such as number of active players, number of active Non-Player Characters (NPCs) in the area, or avatar mobility, influence the server load as well as the characteristics of network traffic. This impact of application state on network traffic characteristics is defined as the "application aspect" by Matijasevic et al. [49] which relates to question: How does the interaction at the application (user) level affect the communication characteristics? Depending on the values of those parameters, different situations can occur in the virtual world.

4.1 Identification of the problem

Many published works in the area of traffic modeling acknowledge the influence of different situations in the virtual world on the traffic patterns [21,38,43]. The following works explore this relationship further.

Chen and Lei [24] examine their collected trace in order to find out the implications of player interactions on generated network traffic. They have established that the distribution of the players in the virtual world is heavy-tailed, which implies that the static and fixed side partitioning mechanisms for the game world are not adequate. They prove that the neighbors and teammates tend to be closer in terms of network topology which is beneficial for the timely delivery of the state updates, and by that, for the fairness of the game. As for the session times, they discover that players with higher degree of social interaction tend to have longer sessions.

4.2 Behavior categorization approaches

Several works try to classify possible situations in the virtual world and analyze MMORPG network traffic separately for each situation. (All classification approaches known to the authors use WoW as a case study.)

Packet level analysis of MMORPG traffic is done by Szabó, Veres, and Molnár [73,74]. They claim that the nature of human behavior has high impact on traffic characteristics and that it influences the traffic both at the macroscopic level (e.g., traffic rate) and at the microscopic level (payload content). They capture and analyze the traffic of WoW and *Silk Road Online* by *Joymax*, and examine the server generated traffic. The states of the virtual world are defined with respect to two criteria, one being the movement (or lack thereof) of the given player, and the other the number of surrounding players (in or out of the cities i.e., densely populated areas). This results in four possible states: *Moving in the city, Moving outside the city, Stalling in the city,* and *Stalling outside the city.* States are identified by active measurements and wavelet analysis. The model is validated by controlled measurements and comparison with the defined states. Secondly, they measure the traffic while capturing in-game video and applying a heuristic algorithm on the character's screen in order to determine in which of the states the character is currently in. The algorithm achieves 68% accuracy. In the third step of the validation, authors perform several measurements using other MMORPGs, such as *Guild Wars*, EVE, and *Star Wards Galaxies.* They present a novel method for classification of the MMORPG traffic on the basis of dynamic signature, by using Deep Packet Inspection (DPI). They presume that the payload segment, which encodes the location of players in gaming environments, shows the same statistical properties as those that characterize human motion models. In general, methods using DPI are quite limited in practice due to the encryption used by game providers to prevent cheating.

Wang et al. propose the following classification: *Downtown*, *Hunting*, and *Battlefield* but do not explain the proposed classes in detail [81]. The traffic of WoW in a WiMAX network is measured and the focus of the analysis is on the performance in terms of application level packet dynamics such as RTT and jitter, and WiMAX link level statistics such as wireless link quality and handovers. The traffic measurements are performed in several scenarios: subway, bus, and campus. For each of the combinations of real and virtual world scenarios, RTT is studied and illustrated by corresponding CDFs. Bandwidth consumption shows significant differences in various virtual world situations (up to 4 times in the downlink direction; 8.93 kbps for Hunting compared to 32.11 kbps for Battlefield). Packet loss is measured in real world scenarios and it has been established that the highest packet losses happen in the subway scenario in the uplink direction, and in the bus scenario in the downlink direction. The same research group has presented another study with slightly different names of the proposed classes: *Downtown*, *Player Versus Environment (PvE)*, and *Player versus Player (PvP)* [16]. While the names are different, the classes themselves are in fact identical. Based on the class specific measurements, authors present models which they implement in NS2 network simulator. In their following work [82], the authors present their traffic models for each category, by using deterministic values for client packet

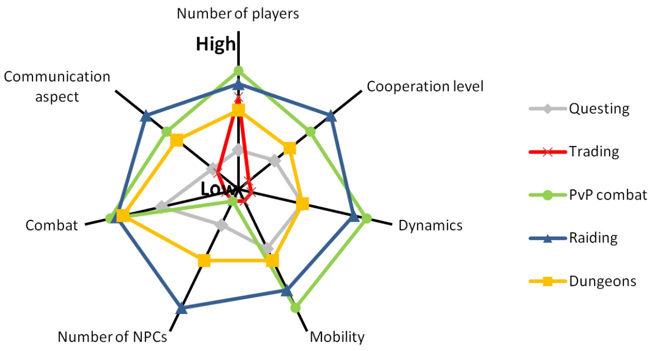


Fig. 6: Classification of user actions [67]

Fig. 7: Relationship between proposed classifications. Legend: ∼ [67], ∧ [57], ∗ [81]

size, and Weibull distribution with different parameters for server packet size, and both client and server IATs.

Park, Kim and Kim propose a following classification of WoW situations: *Hunting the NPCs*, *Battle with players*, *Moving*, and *No play* [57]. Aside from WoW, the authors collect and analyze network traffic traces of FPS game *Quake 3* (Q3). They also define user actions based on the number of players and player behavior for Q3: *Shooting*, *Moving*, *Normal*, and *No Play*. Q3 measurements have been performed on the server, while WoW measurements have been performed on the client, as servers are not publicly available. Data and packet rate, packet size and inter-arrival times have been analyzed. They have concluded that *Battle with players* is the most demanding situation in terms of data rate, and *Hunting the NPCs* is the most demanding situation in terms of packet rate. The size of the packets is modeled by the Exponential distribution on the server side and Normal distribution on the client side, while IATs are modeled with the Normal distribution.

Suznjevic, Dobrijevic, and Matijasevic classify the states of the virtual world through categories of user actions which focus on the player progression, namely: *Questing*, *Trading*, *Player vs Player combat*, *Dungeons*, and *Raiding*. Using WoW as a case study, they analyze [67,69] and model [71] the network traffic of WoW based on the proposed classification of states in the virtual world into the above five user action categories. User actions are categorized based on seven characteristics, as shown in Figure 6: number of players, number of NPCs, mobility of players (in the virtual world), cooperation (interaction) level, dynamics of player input, combat requirement, and communication aspect. The traffic capture is performed on the client. Annotated user action specific traces are used, which contain actions belonging to only one action category. Traces are gathered with the help of six experienced WoW players and consist out of 1.395,940 packets. Properties analyzed in each category include percentage of data packets, bandwidth usage, packet rate, and packet IATs. Authors model the server and the client traffic in all categories starting from the application protocol data units (APDUs), rather than IP packet (datagram) sizes and IATs. The client APDU size is modeled as a deterministic value with several discrete steps, and the server APDU size is modeled by using a combination of two Weibull distributions, or as a Lognormal distribution. The client IATs are modeled by using a combination of Weibull distribution and deterministic values, while the server IATs were the most difficult to model. They are modeled by using a combination of Weibull distribution, Largest Extreme Value distribution, and deterministic values.

In an attempt to summarize and consolidate various classifications proposed in literature, we present them by using Venn diagrams, shown in Figure 7. We note that the classifications proposed in [57,81] do not cover the complete set of possible situations in the virtual world, and are in fact a subset of [67]. Specifically, they do not cover group based actions focused on fighting with NPC opponents (i.e., Dungeons and Raiding in [67]). On the other side, the categorization in [67] is based on player progression so it does not take into account idle players. Also, the *Moving* category proposed by Park et al. [57] is very general, and it is overlapping with all other categories, as in each behavior players move for a while while not actually accomplishing anything (e.g., in raiding when running between enemy NPCs). Additionally, further inspection of traffic properties (CDFs) shows that there is a significant difference between characteristics of *Downtown* in [81], which is the most demanding in that categorization, and *Trading* in [67], which is the least demanding in that proposed categorization. This means that some aspects are not taken into account (e.g., characteristics of different servers) and that models can be improved.

4.3 Social virtual worlds - Second Life

As previously stated, SL is not a MMORPG, but a social virtual world dynamically modified by its users. The virtual world of SL varies very much in terms of number of users and content, and hence also in traffic characteristics. There are several studies which address the issue of impact of user behavior on traffic characteristics in SL. Most approaches take into account both popularity of a certain virtual area (i.e., number of active users) and the movement rate of the observing user.

Fernandes et al. [30] collected and analyzed the network trace of SL for 100 hours on different locations in the virtual world. Authors note that SL requires much more bandwidth than a typical MMORPG, with 500 Kbps required bandwidth for a full experience (that includes an external audio stream), and 200 Kbps for an average experience. Such a difference in the bandwidth requirements stems from game desing: the worlds of MMORPGs are static, and all 3D models are stored on players' computers, while the virtual world of SL is constantly changing as players add their own models (which other players need to download). Authors have also noted a significant difference in traffic requirements of popular vs. unpopular regions of the world (in terms of the number of players). A movement pattern of an avatar has a strong correlation with the required bandwidth usage as *Standing*, *Walking*, and *Flying* result in very different bandwidth requirements. Authors found a relationship between the context of the virtual world (in terms of number of users and players movement pattern) and generated network traffic. The same group of authors [13] have devised traffic models for SL. Based on the notable differences in traffic characteristics for specific user actions and in virtual world characteristics, they model a combination of three categories of player movement (Standing, Walking, and Flying) and two categories describing density of avatars in a zone (Popular and Unpopular). They model four parameters: client and server PS, and client and server packet IATs. Server packet IATs for different combinations of avatar density action are modeled with split distributions combining two or even three distributions, including Beta, Gamma, Lognormal, Extreme, and Weibull distributions. Client IATs are modeled with a Beta distribution. Client PS is modeled as either deterministic or Extreme distribution. Server PS is modeled as a split distribution of 4 models combining Uniform, Exponential, Deterministic and Extreme distributions.

Kinicki and Claypool [40] add an additional transport movement category – *Teleporting*, and also take into account density of objects in the virtual world, as well as population (i.e., number of active avatars). They focus on bandwidth, packet size and packet IATs, stating that the impact of zone characteristics and avatar actions is different than the results obtained by Fernandes et al. [30].

The relationships between application functionality, traffic control system, and the wider network environment have been studied Oliver, Miller, and Allison [55]. Two sets of studies include one based on the traffic generated by a hands-on workshop which used SL (5.1 Gigabits of data in 17 million packets); and a follow-up set of controlled experiments to clarify some of the findings from the first study. They have determined that the average throughput of SL is 231 Kbps, the average RTT is 153 ms, and the loss rate is 0.02%. They monitor all network parameters separately for each of the four mobility states of the avatar: Standing, Walking, Flying, and Teleporting. The results show that the avatars' mobility has significant impact on the characteristics of the network traffic. Also, they note that SL has sophisticated traffic management mechanisms, as it performs application level framing, provides reliability for some packets, tracks RTTs and congestion levels, and reduces bandwidth at high loss levels. SL also has seven channels, where each corresponds to data that fulfill a distinct functionality (e.g., Texture, Asset, and Wind).

To summarize, the SL traffic characteristics are thoroughly studied and it has been shown that they significantly depend on user behavior. While some virtual world areas are almost "deserted", others are quite populated which opens possibilities for more effective, dynamic load balancing of computational and networking resources. The related techniques used in SL could be potentially reused in future MMORPGs featuring user generated 3D content.

5 Summary and Conclusions

As MMORPGs have relatively recently gained wider popularity (i.e., in the last ten years or so), the research focusing on these games is still relatively new as well. The purpose of this paper has been to provide an overview of the state of the art research activities regarding MMORPGs, with respect to network traffic characterization and modeling, and player behavior. Based on the material covered, we summarize the established claims which should be taken into account while conducting research in the area of MMORPGs.

– Traffic characteristics vary significantly depending on the application state and the player actions in the virtual world. The most demanding state should be taken into account when performing calculations based on these characteristics (e.g., network link capacity planning).
– Client traffic and server traffic are highly asymmetrical, with the server traffic typically much larger in volume.
– When performing measurements, it is necessary to note the version of the game, as MMORPGs constantly change and evolve (e.g., in the game version 2.0 of WoW, an ability to fly was added which adds another axis for player movement measurements).
– Several TCP congestion control and flow control mechanisms proved to be unsuitable for the purposes of MMORPGs (e.g., Nagle's algorithm, delayed acknowledgment), while others are highly ineffective (e.g., Fast Retransmit).
– Avatar distribution in the virtual world is not uniform, but rather conforms to the multiple hot spots model, which needs to be taken into account when performing simulations (e.g., for new load balancing algorithms).
– Notable hourly and daily patterns exist in several aspects of player behavior (e.g., number of players, types of player actions).
– Session duration (length) measurement results should be labeled as referring to either character sessions or player sessions in order to convey correct information.

We also list some of the currently open research questions in this area and attempts focusing on solving them.

– Current transport protocols (TCP, UDP, DCCP, and SCTP) are not suitable for MMORPGs due to characteristics of game traffic. The design of the new protocol for MMORPGs is still an open research issue. Some attempts at solving this problem have been presented in [84].
– Detection of bots is an important issue as bots can have an influence on virtual world economy, and significantly reduce the level of satisfaction of regular (human) MMORPG players. Some attempts at solving this problem have been presented in [23].
– Player behavior models in terms of both mobility and player actions (i.e., what exactly players do in the virtual world, when, and for how long). Some attempts at solving this problem have been presented in [70, 60].
– Models for prediction of churn, i.e., players definitively abandoning the game. MMORPG providers try to keep each and every player, and especially "old" players (in terms of time spent in the game), as it is proved that new players have significantly higher churn rates than old players. Some attempts at solving this problem have been presented in [36, 29].
– Influence of player behavior on server architectures and load balancing algorithms. Some attempts at solving this problem have been presented in [53].
– Scalability issues and new techniques for load balancing problems in cases where a large number of avatars is populating a small fraction of the virtual world. Some attempts at solving this problem have been presented in [62].
– Relationship between player behavior and perceived QoE, as same QoS levels will not equally satisfy a player performing a simple and repetitive task (e.g., picking virtual flowers), and a player trying to perform a highly complex task (e.g., trying to defeat a raid boss (i.e., highly complex NPCs)) which requires a possibly large group of coordinated and highly organized players. Some attempts at solving this problem have been presented in [67].

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