On The Scaling Characteristics of MMORPG Traffic

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Abstract:

In this paper a comprehensive scaling analysis of the traffic of the four most popular Massively Multiplayer On-line Role Playing Games (MMORPG) is presented. The examined games are World of Warcraft, Guild Wars, Eve Online and Star Wars Galaxies. Both server and client generated traffic are analyzed in details. Our study reveals the basic statistical properties of the investigated games focusing on the correlation and scaling behavior.

Although the examined games are all from the same genre and such basic statistics such as the mean packet rate, variation of the packet rate, skewness of the packet rate distributions fall into the same magnitude, the games exhibit diverse traffic characteristics. We have found that in spite of the fact that some similarities can be found among the scaling characteristics of these games they show versatile scaling properties and the games can not be treated with one common model.

Introduction

Today's Internet usage tends toward to serve the expansion of the entertainment industry. Beside the content-delivery traffic (e.g.~web, P2P), significant traffic appeared which is generated by online games. Massive Multiplayer Online Role Playing Games (MMORPG) attract the most users playing simultaneously in virtual worlds over the Internet.

Earlier studies focused on games being popular at that time. These games include the popular first person shooters, e.g. Counterstrike was analyzed in [1]. Today most of the gaming traffic is generated by massively multiplayer online games thus such works treating with the new type of traffic appeared. Chen et al. analyzed ShenZhou Online, a mid-scale, commercial MMORPG in Taiwan [2]. They extended their work in [3] where they performed scaling analysis on the measurements. They explained the scaling results with the fact that an ON-OFF model can be constructed based on the results of the analysis where ON and OFF periods are in connection with the players active and idle times indirectly. In [4] authors analyzed Lineage II which was one of the world's largest MMORPGs in terms of the number of concurrent users at that time. In [5] authors took Ragnarok Online, and studied the traffic generated by mainstream game bots and human players. In [6] authors used CrossFire, an open source MMOG to evaluate their performance model. All of these works used packet level network traces and statistical methods for traffic characteristics analysis.

However, situation changed recently. According to [7] the top game having the most active subscribers is World of Warcraft. The number of active subscribers is four times higher than Lineage II. We decided to analyze the following games from the charts of [7]: World of Warcraft, Eve Online, Star Wars Galaxies and Guild Wars. There are several reasons behind this decision. All of these games are commercial, and it was only recently possible to access the games via Internet and play with them free during a trial period. In addition, the target market of the games used in previous analysis was definitely the Asian market. However, we can hardly come across with any of the traffic of those games in a European or American network.

The motivation of our work is to understand the traffic characteristics and, especially, the scaling behavior of the traffic generated by the selected games. Although the traffic rates generated by the clients are low comparing to other applications, their aggregation on the server side can become significant due to the large population of players. The scaling characteristics of the internet traffic, with special attention to the growing gaming traffic, can have significant impact on network performance and engineering.

Measurements

The measurements took place on a client machine connected to a campus network which access the Internet via a 100MB FDDI. The network parameters of this connection is far above the capabilities of such a network for which these games are designed for, thus we can assume that we do not have to deal with any parameter change in the game traffic due to the network inadequacy. The advantage of the measurement configuration is that we can observe the client network traffic practically without loss of packets and network delay. The measurements were committed in the 19-20 hour periods on weekdays in January, 2007. We have measured both the downstream traffic from the server to the client (we will call it server traffic throughout the paper) and the upstream traffic from the client to the server which will be called client traffic. The network traffic of the client machine running the games was captured by Wireshark with microsecond accuracy.
The traffic of the different games can be seen in Figures 1-4. As the statistical methods which were applied on the measurements presume the stationarity property of the examined data series, the selected intervals for examination are showed on the figures.

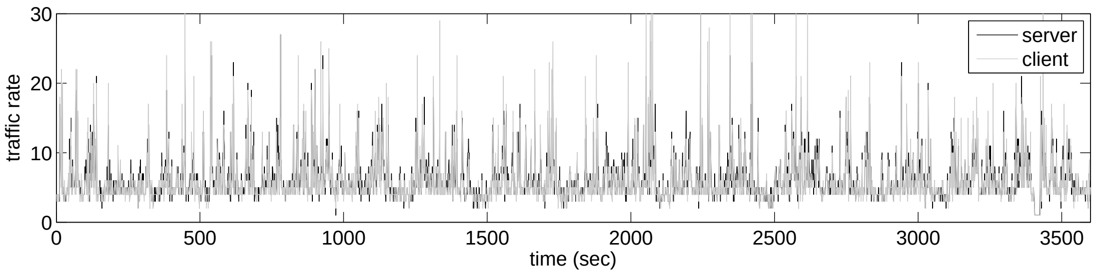

Fig. 1. World of Warcraft traffic intensity (packets/sec), selected inteval:1100-2000

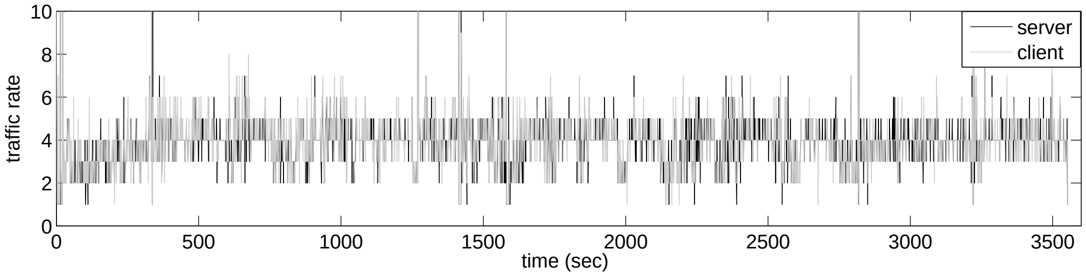

Fig. 2. Guild Wars measurement traffic intensity (packets/sec), selected inteval:1600-2800

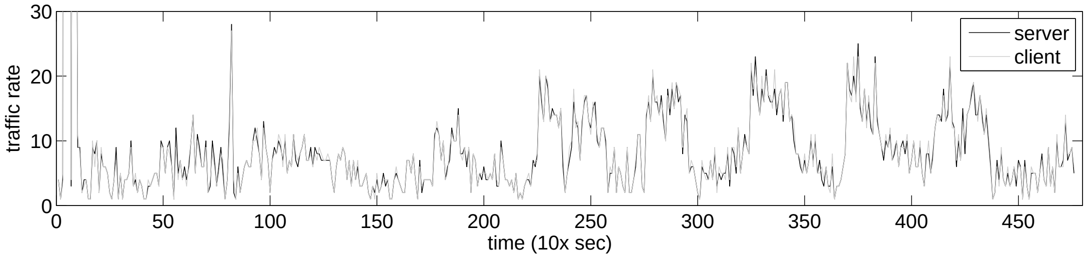

Fig. 3. Eve Online measurement traffic intensity (packets/10 sec), selected inteval:50-450

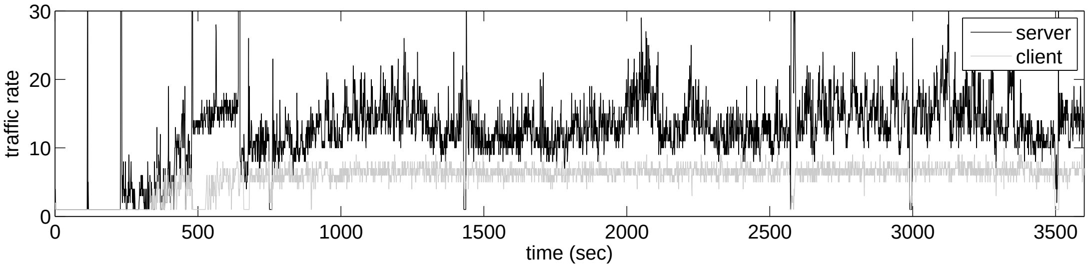

Fig. 4. Star Wars Galaxies measurement traffic intensity (packets/sec), selected inteval:1500-2000

Basic traffic characteristics

Observing the Probability Density Function (PDF) of the interarrival times of the packets derived from the clients to the server there are distinct values for some specific packet inter-arrival time values. These are the effects of the internal working mechanism of the game client application as the measurement setup does not add any delay to the captured packets derived from the clients. All the games have a high probability value about the 200 msec packet inter-arrival time. This value was a reasonable design decision, as MMOGs designed to run smoothly even with 1250 msec latency in game play thus with the 200 msec periodicity even a retransmission fits into this interval length. World of Warcraft and Guild Wars have peaks at their pdf at about 300 msec and Star Wars Galaxies has a high peak at 140 msec. This lower packet inter-arrival time can be explained by the situation that Star Wars Galaxies uses UDP protocol with plenty of small packages, thus the communication model is different from the other analyzed games. Eve Online generates packets much rarely than the other games thus the probability of high packet inter-arrival time values decreases slower.

In case of the server packets the very low packet inter-arrival time values is due to the fragmentation of packets when a data burst is transmitted towards the client. The identification of packet inter-arrival time values can be effectively used during traffic classification.

Investigating the probability density function of the packet payload sizes it can be experienced that the zero and few-byte payloads occur frequently both at the client and at the server side. One reason for this is that at least the TCP packets have to be acknowledged even if the party itself does not want to send data. Another reason is that the game protocol is constructed as an overlay protocol on TCP. As an example, we can check the general structure of the World of Warcraft (WoW) packets, where we can see

that the TCP data carries a 4 byte WoW packet header if it is a server packet and 6 byte if it is a client packet. This header contains a WoW packet type field which is necessary for parsing the rest of the packet accordingly. The WoW packet header is encrypted. If either the client or the server sends a packet apart from the TCP acknowledges, these packets have at least 6 or 4 bytes length even if they do not carry any game data.
We can confirm earlier works which found that comparing the client and server packet size distribution the client packets are smaller as it contains the commands of one player, while server packets convey nearby the actions of nearby players and monsters as well as system messages.

Comparing the probability density function of the server and the client packet rates we can find that those games which applies TCP for communication has similar pdf, while Star Wars Galaxies which uses UDP for communication has very distinct pdf characteristics as the probability of high packet rate on the server side is higher than on the client side. Other basic statistical descriptors are showed in Table 1.

		World of Warcraft	Guild Wars	Eve Online	Star Wars Galaxies
	Duration (sec)	900	1200	4000	500
Server	Packet number	5756	4516	3391	6129
	Avg. packets/sec	6.39	3.76	0.84	12.26
	Avg. packets size (bytes)	220.25	183.19	261.18	156.47
	Size (bytes)	1267766	827319	885680	959036
	Average bwidth kbits/sec	11.01	5.38	1.73	14.98
Client	Packet number	5582	4597	3429	3169
	Avg. packets/sec	6.21	3.83	0.86	6.34
	Avg. packets size (bytes)	71.12	57.58	64.41	77.25
	Size (bytes)	39990	264705	220870	2448806
	Average bwidth kbits/sec	3.45	1.72	0.43	3.82

Table 1 Basic data of the selected traffic trace segments

Long-range Dependence Analysis

The Long-Range Dependent (LRD) property of a traffic flow is revealed in the power law decay of the autocorrelation function at large lags, i.e. $r(k) \sim c|k|^{2H-2}, k \to \infty, H \in (0.5,1)$ and c is constant. The degree of this slow decay is determined by the Hurst parameter (H). Intuitively, long-range dependence measures the memory of a process. For LRD data the ACF decays very slowly (power-law decay). On the contrary, Short-Range Dependence (SRD) is characterized by quickly (exponential-like) decaying correlations.

Among the several statistical methods of LRD testing [10] we choose periodogram analysis, R/S analysis, variance of residuals, variance-time plot, and the Whittle estimator and use the logscale diagram based on the wavelet transform [8] to verify the results.

The results of our LRD analysis can be found in Table 1. We can see that World of Warcraft traffic is strongly long-range dependent for the server traffic. However, the LRD tests results have not confirmed for the client traffic due to the statistical inaccuracy. In case of Guild Wars, the client traffic shows LRD property, but in case of the server traffic the test can not be performed due to the lack of data in higher time scales. Star

Wars Galaxies server traffic shows LRD property with parameter H=0.75. The client traffic can not be estimated due to similar reasons as in the case of Guild Wars server traffic. In case of Eve Online server traffic the higher ranges can not be used for LRD parameter estimation due to the lack of data in that ranges. The same statements are true for the client traffic of Eve Online. The summary of the results of the long range analysis can be found in Table 2.

		World of Warcraft	Guild Wars	Eve Online	Star Wars Galaxies
Server	Arby-Veitch	0.84	-	-	0.71
	Periodogram	0.89	-	-	0.72
	R/S	0.86	-	-	0.80
	Variance of residuals	0.89	-	-	0.85
	Variance-time plot	0.85	-	-	0.75
	Whittle estimator	0.81	-	-	0.70
	Avg. Hurst parameter	0.86	-	-	0.75
Client	Arby-Veitch	-	0.78	-	-
	Periodogram	-	0.85	-	-
	R/S	-	0.79	-	-
	Variance of residuals	-	0.80	-	-
	Variance-time plot	-	0.78	-	-
	Whittle estimator	-	0.75	-	-
	Avg. Hurst parameter	-	0.79	-	-

Table 2 Summary or the long-range dependence analysis (n.a.=statistical results non reliable due to insufficient sample size)

Scaling Analysis

Scaling properties of traffic can be efficiently investigated by multifractal analysis via wavelet-based methods [8]. The discrete wavelet transform represents a data series X of size n at a scaling level j by a set of wavelet coefficients $d_X(j,k), k=1,2,...n_j$, where $n_j = 2^{-j}n$. Define the q^{th} order Logscale Diagram (q-LD) by the log-linear graph of the estimated q^{th} moment $\mu_j(q) = \frac{1}{n_j}\sum_{k=1}^{n_j}|d_X(j,k)|^q$ against the octave j. Linearity of the LDs at different moment order q suggests the scaling property of the series, i.e. $\log_2 \mu_j q = j\alpha(q) + c_2(q)$ where $\alpha(q)$ is the scaling exponent and $c_2(q)$ is a constant. In our test results we plot $y_j = \log_2 \mu_j(q)$ for $q=2$ which is called the second-order logscale diagram (LD). The plot of $\alpha(q)$ against q can reveal the type of scaling [9]. In case of *monofractal* scaling $\alpha(q)$ varying linearly with q while for *multifractals* the variation is non-linear. For testing this behavior the Linear Multiscale Diagram (LMD) can efficiently be used which is defined as $h_q = \alpha(q)/q - 1/2$.

It can be seen that the logscale diagram of the **World of Warcraft** server traffic is approximately linear (Figure 5) for the whole range and supporting the LRD property suggested by the LRD tests. Since the linearity holds for the whole investigated range it also suggests possible statistical self-similarity over these time scales. The linear

multiscale diagram depicted in Figure 13 confirms this observation. The LMD of World of Warcraft soon takes up a stabilized value around $h_q = -0.16$ which gives an estimate of $H = 0.84$ since $H = h_q + 1$ for all q in case of self-similar traffic.
The estimated value is in accordance with the values calculated by the LRD tests (*H*=0.86). We can conclude that World of Warcraft server traffic is not only LRD but the statistical *self-similarity* is a good model for this type of traffic in these time scales. The selected range of the time scales for analysis based on the fact that there is not a reasonable rate function below the 1 sec time intervals, thus the low packet rate of the traffic imposes a lower bound for the analyzed time scale. On the higher time scales we selected the longest stationer parts of the measurements but even with this method it can not be gained enough samples from higher time scales than we show in this study.

A different behavior can be observed for the World of Warcraft client traffic. Examining the logscale diagram in Figure 6 we can only find scaling region in the range between $j = 1$ and $j = 4$ (1 sec-16 sec). The multiscale diagram (Figure 14) reveals the scaling type in the range between $j = 1$ and $j = 4$ (1 sec-16 sec): the non-linear LMD plot shows *multifractal* behavior. The multifractal behavior frequently found together with the non-Gaussian like marginals of the rate distribution. This property holds for this case too. The kurtosis (13.53) and skewness (2.89) are also far from the Gaussian-like distributions. (A Gaussian distribution has kurtosis and skewness metrics 3 and 0, respectively.) For the upper time scales (above 16 sec) no scaling property can be found. It is important to note that self-similarity is a characteristic property for higher time scales than 50-100 msec e.g. in the case of the round trip time of a TCP packet. Below this limit the fractional property can be found, but in our case the multifractal property of the client traffic can be observed as large time scales as 1-16 sec.

The logscale diagram of **Guild Wars** server traffic (Figure 7) can be divided into two ranges: $j = 1 - 4$ (1 sec - 16 sec) and $j = 4 - 6$ (16 sec - 1 min) where scaling region can only be detected in the lower ranges. Depicting the LMD of the 1-4 ranges in Figure 15 it can be seen that it has the same value over all the investigated moments. Thus it can be concluded that Guild Wars server traffic can be modeled with a *monofractal* model with *h*=0.63 scaling parameter in these time scales.
Examining Figure 8 we can see that the logscale diagram of the Guild Wars client traffic is approximately linear suggesting self-similar scaling over all the investigated time scales. The LMD in Figure 16 shows us that the Guild Wars client traffic indeed has *self-similar* scaling. The estimated *H*=0.78 from the LD diagram is in good accordance with the estimated *H*=0.79 obtained by the LRD tests. Because of the self-similar scaling we can expect a Gaussian-like rate distribution. Both the shape of the rate distribution and also the estimated kurtosis (3.09) and skewness (0.04) metrics confirms that our expectation is true.

The logscale diagram of **Eve Online** server traffic plotted in Figure 9 can be divided to two ranges where the scaling property can be examined: 1-3 (10 sec-80 sec) and 3-5 (80 sec-over 5 min). The range between 3-5 consists very few data thus the estimators are very inaccurate in this range. Analyzing the range between 1-3 by the multiscale diagram (in Figure 17) it can be seen that the calculated scaling parameter is around 0.54 which suggest a non-scaling *noise-like* behavior. Thus we can conclude that there is *no scaling* property of Eve Online server traffic for the whole range.

The similar statements are true for the client traffic as well: the scaling parameter between 1-3 (10 sec-80 sec) is *h*=0.52, and range between 3-5 (80 sec-5 min) contains few data (Figure 10, 18), thus we can conclude that there is *no scaling* property of Eve Online client traffic for the whole range.

Investigating the server traffic of **Star Wars Galaxies** it can be seen on the logscale diagram in Figure 11 that it is also approximately linear for the whole range and in Figure 19 the LMD gives values around $h_q = 0.29$. Thus Star Wars Galaxies server traffic can also be modeled with a statistical *self-similar* process with $H = 0.71$ estimated by the LD plot. This estimation matches the $H = 0.75$ obtained by the LRD tests. The self-similar property also comes together with the Gaussian-like marginals as could be seen in the rate distribution curves and also from the estimated kurtosis (3.23) and skewness (0.45) metrics.

Looking at the logscale diagram in Figure 12 of Star Wars Galaxies client traffic we can divide two ranges where the scaling property can be examined: 1-3 (1 sec - 8 sec) and 3-5 (8 sec - 1 min). The range between 3-5 consists so few data thus the estimators are very inaccurate in this range. Examining the range between 1-3 by the multiscale diagram (in Figure 20) it can be seen that the calculated scaling parameter is around 0.5 which suggests a non-scaling *noise-like* behavior. Thus we can conclude that there is *no scaling* property of Star wars Galaxies client traffic for the whole range.
In Table 3 the summary of the scaling analysis can be found.

	Server	Client
World of Warcarft	self-similar H=0.86 (1 sec-1 min)	multifractal (1 sec-16 sec), no scaling (above 16 sec)
Guild Wars	monofractal h=0.63 (1 sec-16 sec), no scaling (16 sec-1 min)	self-similar H=0.79 (1 sec-1 min)
Eve Online	no scaling	no scaling
Star Wars Galaxies	self-similar H=0.75 (1 sec-1 perc)	no scaling

Table 3 Summary of the scaling analysis

Conclusion

In this paper we have analyzed four popular games traffic in both server and client directions. We have presented the important statistical characteristics of these games and we have carried out a comprehensive scaling analysis including long-range dependence analysis with several tests and a detailed scaling analysis by a wavelet-based multifractal analysis.

We have found different scaling properties of the investigated MMORPG traffic types. The server traffic of World of Warcraft is statistically self-similar with Hurst parameter around 0.86. However, the client traffic of World of Warcraft is multifractal below 16 sec time scales. The Guild Wars client traffic is statistically self-similar with Hurst parameter around 0.79. The server traffic in this case also shows scaling behavior over small time scales, namely, it has monofractal scaling. Star War Galaxies server traffic has self-similar scaling with Hurst parameter 0.75. However, this game traffic do not have this scaling characteristics from the other direction. Finally, both server and client traffic of Eve Online have no scaling behavior.

As a conclusion we have found that in spite of the fact that some similarities can be found among the scaling characteristics of these games they show versatile scaling properties. From these results we conjecture that the emerging network traffic in the Internet cannot be classified by a typical gaming traffic behavior but rather will depend on the characteristics of the actual dominant gaming application.

Our future work will address the analysis of the network game traffic aggregates and the modeling of these traffic types. Furthermore, we would like study the network performance implications of these game traffic characteristics.

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Appendix

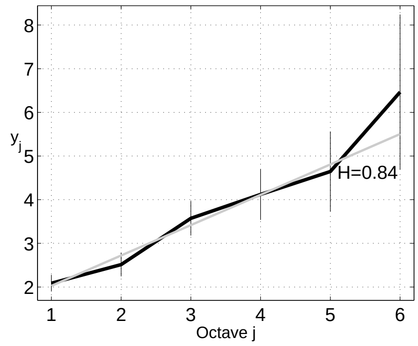

Fig. 5. World of Warcraft server logscale diagram covering timescales from 1 sec to 1 min

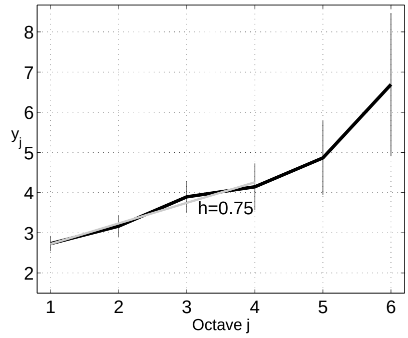

Fig. 6. World of Warcraft client logscale diagram covering timescales from 1 sec to 1 min

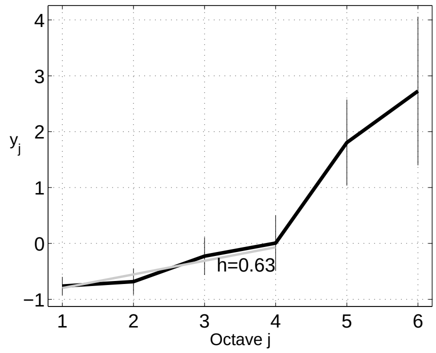

Fig. 7. Guild Wars server logscale diagram covering timescales from 1 sec to 1 min

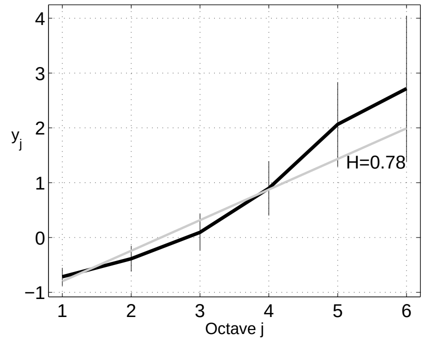

Fig. 8. Guild Wars client logscale diagram covering timescales from 1 sec to 1 min

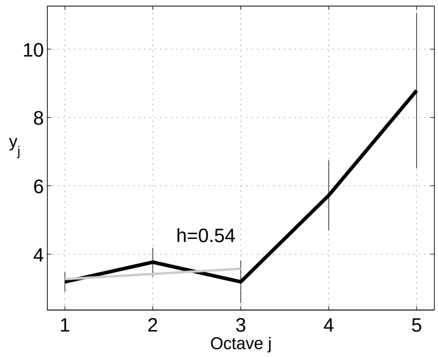

Fig. 9. Eve Online server logscale diagram covering timescales from 10 sec to 1 min

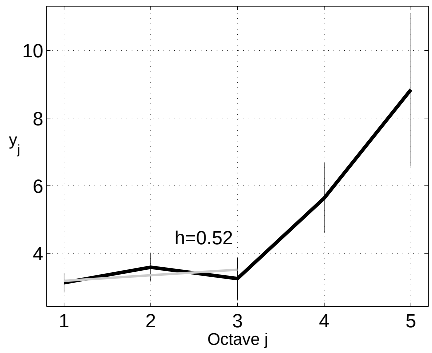

Fig. 10. Eve Online client logscale diagram covering timescales from 10 sec to 1 min

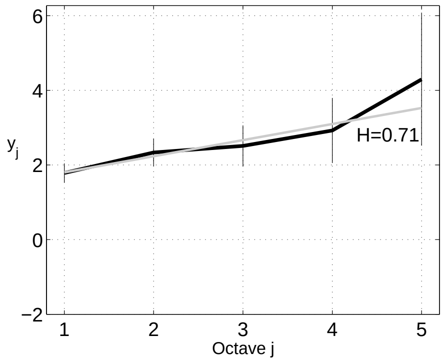

Fig. 11. Star Wars Galaxies server logscale diagram covering timescales from 1 sec to 32 sec

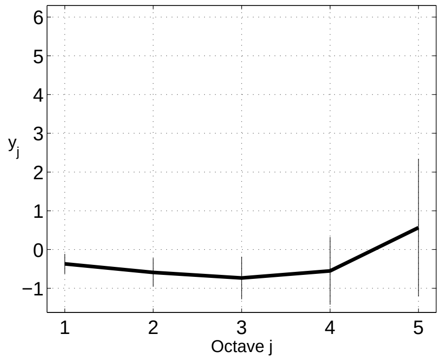

Fig. 12. Star Wars Galaxies client logscale diagram covering timescales from 1 sec to 32 sec

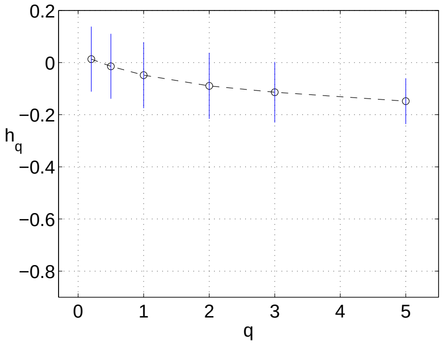

Fig. 13. World of Warcraft server multiscale diagram depicted on the time scales between 1 sec and 1 min

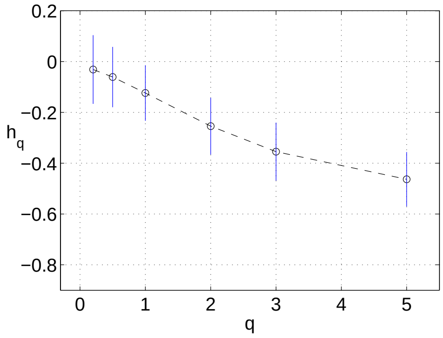

Fig. 14. World of Warcraft client multiscale diagram depicted on the time scales between 1 sec and 16 sec

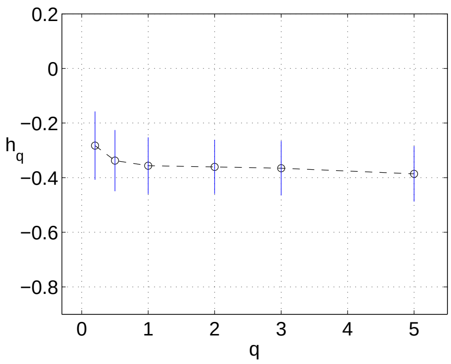

Fig. 15. Guild Wars server multiscale diagram depicted on the time scales between 1 sec and 16 sec

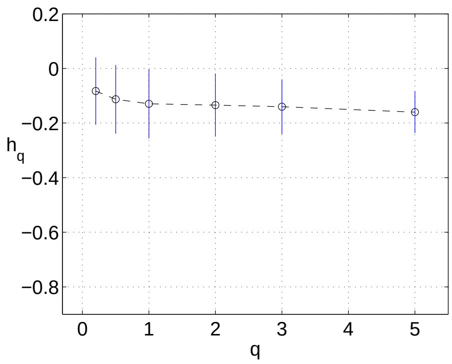

Fig. 16. Guild Wars client multiscale diagram depicted on the time scales between 1 sec and 1 min

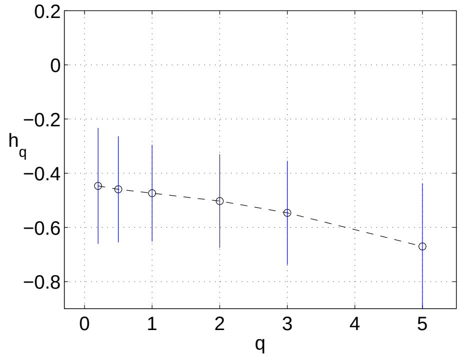

Fig. 17. Eve Online server multiscale diagram depicted on the time scales between 10 sec and 1 min

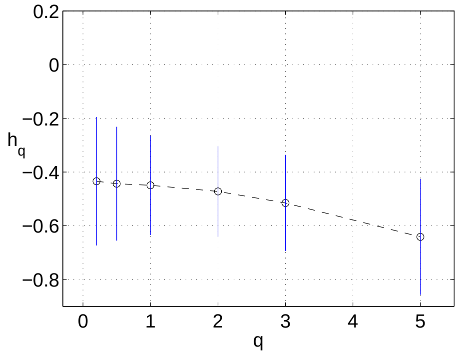

Fig. 18. Eve Online client multiscale diagram depicted on the time scales between 10 sec and 1 min

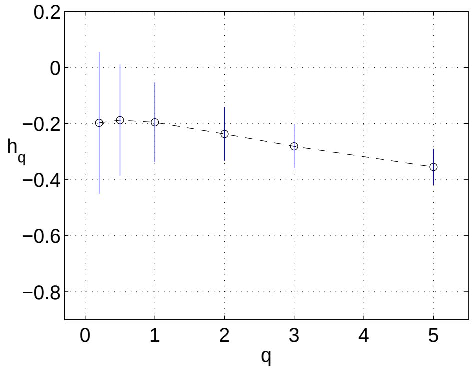

Fig. 19. Star Wars Galaxies server multiscale diagram depicted on the time scales between 1 sec and 32 sec

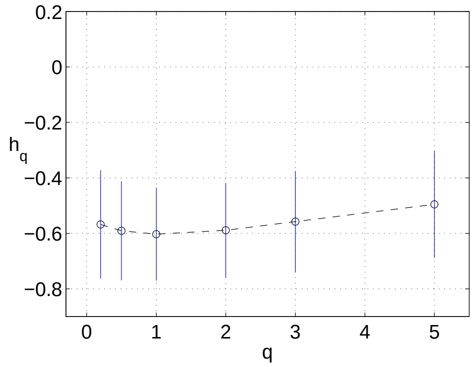

Fig. 20. Star Wars Galaxies client multiscale diagram depicted on the time scales between 1 sec and 8 sec