# Characterizing Mobility and Contact Networks in Virtual Worlds

Felipe Machado, Matheus Santos, Virgílio Almeida, and Dorgival Guedes

Department of Computer Science
Federal University of Minas Gerais
Belo Horizonte, MG, Brasil
{felipemm,matheus,virgilio,dorgival}@dcc.ufmg.br

**Abstract.** Virtual worlds have recently gained wide recognition as an important field of study in Computer Science. In this work we present an analysis of the mobility and interactions among characters in World of Warcraft (WoW) and Second Life based on the contact opportunities extracted from actual user data in each of those domains. We analyze character contacts in terms of their spatial and temporal characteristics, as well as the social network derived from such contacts. Our results show that the contacts observed may be more influenced by the nature of the interactions and goals of the users in each situation than by the intrinsic structure of such worlds. In particular, observations from a city in WoW are closer to those of Second Life than to other areas in WoW itself.

**Keywords:** Multi-player On-line Games, Virtual Worlds, social networks, complex networks, characterization.

## 1 Introduction

Virtual worlds are an important emerging form of social media that have recently caught the attention of the research community for their growth, their potential of applications and the new challenges they pose [1,2]. According to the companies responsible for those worlds, as of December 2008, World of Warcraft (WoW) is being played by more than 11.5 million subscribers worldwide and Second Life total residents are more than 16.5 million. Other data suggests that there are more than 16 million players of massively multi-player on-line games (MMOGs), where players control one or more characters in virtual worlds. Not only that, but users spend a significant amount of time on-line: in Q3/2008, residents spent 102.8 million hours in Second Life. Each virtual world fosters the creation of an active market both inside them and in other sites in the Internet, moving billions of dollars in the entertainment industry [3].

The environments provided by such virtual worlds are usually complex, providing a variety of opportunities for players to interact, fight and develop their characters. The virtual worlds are often divided in zones that may represent continents, islands, cities and buildings, where characters must move. Players may be forced to cooperate with others in order to achieve certain goals, and have to

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fight elements of other groups according to the rules of each environment. Even Second Life can be analysed in such a manner, although in that world there are no explicit competitive situations other than those arising in usual social interactions.

All the possibilities offered by those environments create a highly complex virtual reality where a variety of characters seek different goals. Although some aspects of the virtual worlds may be quite detached from reality (like the multitude of different forms of intelligent life and the presence of magic forces), other aspects can be quite similar to the real world. After all, characters are controlled by real people, and interactions are often based on rules also existing outside the virtual environments. Information extracted from such virtual worlds may be directly useful to understand the way users behave in them, but can also be applied to other problems. For example, information about user mobility may be used in studies of how viruses spread among people, how information disseminates through their contacts, or how malware may spread among wireless devices carried by them [4].

Our goal in this work is to provide a first analysis of those worlds in terms of the way players move through the game and how they interact. That is achieved through a spatio-temporal analysis of mobility patterns in both worlds. From those patterns, we derive the social networks based on the users' contact patterns and study them considering the similarities and differences of the two environments. While in Second Life interactions are mostly cooperative, in WoW they also have a competitive nature, leading to mixed behaviors. That difference is visible in some of the results. As previously mentioned, the information we provide here can be useful for those interested in the development and analysis of virtual worlds, as well as an input for experiments that depend on movement and contact data for real people, such as in epidemiological studies or research on mobile networks, for example.

In the Sections that follow, we start by discussing related work in Section 2. Section 3 provide a general description of the virtual worlds considered, while Section 4 discusses our approach to monitoring them and deriving the metrics we used. The subsequent Sections that follow present the results of our analysis in terms of mobility patterns and contact social networks. Finally, Section 7 provides some conclusions and discusses future work.

## 2 Related Work

Virtual worlds have recently become the focus of researchers looking for data that could be used to model real world mobility patterns. The Second Life virtual environment has been monitored to collect information about avatar movements to mirror movement in enclosed spaces [5]. Metrics used included time to first contact, contact time, inter-contact time, and covered distance, among others. They also analyzed the users' contact network using complex networks metrics such as node degree, network diameter and clustering coefficients. We use similar metrics in this work.

Characterization of on-line games has been an interest for some time now, but a lot of effort has been focused on studying the network traffic produced by them, not in understanding the mechanics of their virtual worlds [6,7,8]. In relation to the particular worlds considered in this study, there has been previous work characterizing Second Life and World of Warcraft from the point of view of the users, by collecting traffic in the client applications [9,10], but again with little insight into the virtual worlds themselves. With that in mind, this work is, to the best of our knowledge, the first one to consider two different virtual worlds with different interaction patterns and objectives. It is also the first one to consider the behavior of avatars in *World of Warcraft* from a social network perspective derived from their contacts.

## 3 Virtual Worlds: Background

Both environments considered can be seen as examples of massive multi-player on-line games (MMOGs) based on the Role-Playing Game model (RPG). In such games, players perform their roles through their characters in the game, which interact based on behavioral rules defined by the game environment. For the sake of completeness, this Section provides a brief description of both worlds.

### 3.1 Second Life

In Second Life, each user controls a virtual character (avatar) that can own objects, real estate, stores, etc. Usually there is no concept of game levels, since the game is entirely focused on social interactions. Hierarchies and class divisions are left for the players. Basically, an avatar sets itself apart from others based on its looks and its possessions.

Differently from a traditional RPG, there are no clearly stated goals to Second Life, no missions or tasks defined by the game for the users to complete. The idea is just to allow users to interact socially, talking, performing collective activities, or trading, for example. Users can create virtual groups, which are just used to bring together users with common interests, like the appreciation for a certain location, the desire to meet other people or just as a means to make it simpler to keep contact over time. Avatars can become friends with others, leading to an underlying social network, although the environment does not offer tools to build such networks explicitly.

The game territory is quite large, being composed by different continents and many islands. All of it is divided in smaller regions called *lands*, usually in the form of 256 meter-sided squares. Each *land* has a defined maximum occupancy and is kept associated with a specific server in order to make load distribution simpler. Management of user actions are therefore distributed among the servers.

### 3.2 World of Warcraft

*World of Warcraft* (WoW) adheres strongly to the concept of RPG. It takes place in a virtual world divided in large continents, each one with its special

characteristics and sub-divisions. In the game, each user can have multiple characters, but can control only one at a time. The goal of the game is, just like in most RPGs, to evolve the characters based on a hierarchy defined by the game and to defeat the enemy, which can be another player or a programmed entity running on the game servers. For that end there are different resources and possibilities, like items that characters can obtain during the game, their professions and special abilities they can develop. To help characters in their quests and facilitate interaction and trade among users, various cities exist in the territories offering supplies, shelter and training for characters.

In WoW, each character belongs to one faction, race and class. They must belong to one of the two existing enemy factions, the *Horde* and the *Alliance*, bound to fight each other. For that reason, a meeting of characters of different factions cannot be collaborative, but instead must be surrounded by a clear form of dispute. Cities can belong to one of the factions or declare themselves neutral grounds, the only place where members of different factions can meet without open confrontation. The auction houses in such cities can mediate trade between the factions.

Continents are divided in *zones* with different shapes larger but similar to Second Life's *lands* in the way they restrict movements between them to a few points of transit. In that way, each zone can be controlled independently of the others. *Eastern Kingdoms* and *Kalimdor* are the older continents in the game, while *Outlands* is a newer continent added during an expansion named the *Burning Crusade*. There is also the concept of *instances*, regions of the map that are duplicated to restrict the occupancy to certain groups each time. If various groups go to a certain region to complete a mission, game servers instantiate one copy of that region for each group, in case the goal is to allow each group to work on the mission without affecting the others' progress. That leads, in practice, to areas with externally controlled populations.

## 4 Methodology

In order to understand the behavior of characters in WoW and Second Life, we collected data from WoW at different levels, so we could analyse behavior in terms of the large continents, controlled regions (instances) and a city, which we expected to be a region with characteristics closer to those of an island in Second Life.

Table 1 shows some general information about the data collected for each of the virtual regions we considered. The headers used for each of the first five columns refer to elements from WoW: main continents (*Eastern Kingdoms*, *Kalimdor*, and *Outlands*), an instance of a region (*Instance 18*), and a city (*Stormwind*). The last column refers to *Second Life*. Rows show, for the duration of the logs, the total number of distinct characters seen in each region, the average and maximum number of concurrent users actually on-line, and the average session length in hours. The two worlds considered differ significantly in their operations, what led to the use of different data harvesting techniques. The details of each process are discussed next.

**Table 1.** General information about the collected data

| | WoW | | | | | S.L. |
|---|---|---|---|---|---|---|
| | E. K. | Kal. | Inst18 | Outl. | SW. | |
| Characters | 1276 | 1039 | 750 | 611 | 511 | 511 |
| Avg. concurrent users | 109 | 105 | 88 | 56 | 109 | 31 |
| Max. concurrent users | 340 | 299 | 225 | 123 | 340 | 49 |
| Avg. session length (h) | 1.4 | 1.6 | 1.6 | 1.4 | 1.2 | 0.05 |

To collect data from Second Life we implemented a client for the game using the *libsecondlife* library[1]. This automated client connects to the server as a player, interacting with the world following a pattern defined by the programmer. For this work, the client moved in large circles around the center or the territory, since it was found that a moving avatar draws less attention.

Once the resulting avatar reaches one of the lands it begins receiving information about the general conditions of the land and all other characters in that region (their IDs, their position relative to the land and whether they are online or offline. The client stores that information once every five seconds in a record containing the number of online users in that land at the time, followed by a list with character ID and position for each avatar. The logs used in this work were selected to hold a continuous 24 hour period. The region used was the Dance Island[2], a popular location in Second Life which contains a dance floor and a bar, among other things.

Besides the official World of Warcraft (WoW) game servers, there are currently other versions of those servers, developed through reverse engineering, maintained by users around the globe. For this work we used a message log obtained from one of those user-maintained servers for version 3.5 of the game. The log was created by instrumenting the private *Mangos* server to log every network message received or sent by it over a 24 hour period. That resulted in a 33 GB data log with more than one hundred million messages, being 15 million sent from clients to the server, and approximately 96 million sent by the server. If the server showed any interruption in its execution the period of the fault was removed from the logs and users returned to their activities where they had left them at the moment of the problem, avoiding any impact to the players movements.

Coordinates in the WoW messages are relative to the main continents and instances the characters are in, so there is no global coordinate system that can be equally applied to all characters. To take that into account, all the following analysis considered each continent separately. As previously mentioned, we considered the continents *Eastern Kingdoms*, *Kalimdor*, and *Outland*. We also analysed separately one of the major cities in the game, *Stormwind*, to compare with the results from *Second Life*, since a city in WoW offered an area more similar to a *land* than a complete continent. Finally, we also added an instance of a replicated region of the game, identified as *Instance 18*, where the number of players was controlled by the game server.

[1] http://www.libsecondlife.org/

[2] `http://slurl.com/secondlife/Dance%20Island/`

An anomaly identified in the game, when compared to the real world, was the presence of different forms of *teletransportation*[3]. In some of the analysis, we experimented with removing that functionality from character behavior to try to get patterns closer to the real world, since teletransportation would allow them to travel unlimited distances in practically no time, something clearly impossible in the real world. To achieve that, each time a character used teletransportation, disappearing from one location and materializing at another one, we considered that the first character left the game at the earlier position and a new one entered the game at the materialization spot. We also analyzed the movements as they happened originally, with teletransportation.

Once data was collected from WoW, we extracted from the log all messages carrying character positions with the ID of the character, its position and the message timestamp. That information was then processed to create a final log with the same format of that created for Second Life, with all active characters' positions recorded every five seconds. After a single record format was available for both worlds they were processed using the same algorithms to derive information such as covered distances, demographic density and contact events. Contacts were considered to occur whenever two characters were closer than a certain distance $r$, considered 10 meters in this case. That definition allows us to consider not only direct character interaction but also close encounters, which have been identified in the literature as relevant for multiple purposes, such as epidemiological studies and wireless network interactions [11]. From the contact information we built the network of contacts, one of the main focus of this paper, and derived also a temporal analysis of contacts. For the temporal analysis, we computed *time to first contact*, the time it took characters to establish their first contact in the environment, *contact time*, the times characters spent in contact with others, and *inter-contact time*, the times between two successive contacts by each pair of characters. The results of the analysis of the metrics derived are discussed in the following Sections.

## 5 Spatio-temporal Analysis

### 5.1 Spatial Analysis

In this section we analyze and compare character movements in the two worlds, both in terms of distances traveled and demographic densities.

**Distances traveled.** Figure 1 shows distances traveled (both as a probability density function, PDF, and a cumulative probability density function, CDF) for both worlds in log scale, with and without teletransportation in WoW. As expected, based on the dimensions of each area, probability of short travels is higher in Second Life, while distances in WoW with teletransportation may be significantly larger.

[3] In Second Life avatars can also use teletransportation, but only between lands. Since we consider only one land, such events were seen as a user leaving the region.

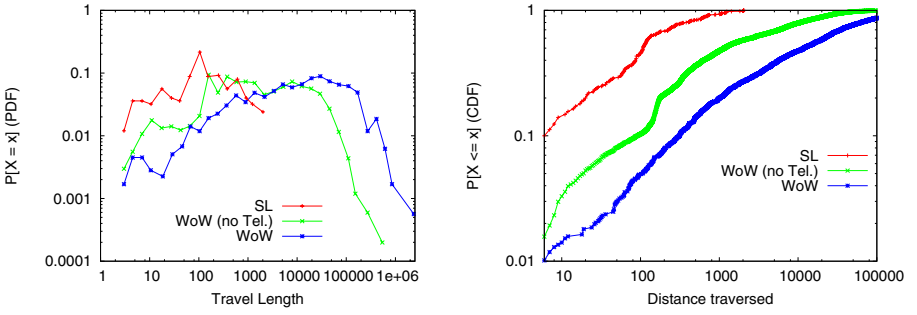


**Fig. 1.** Probability distributions (simple and cumulative) for distances traveled by characters in each region

The reason for shorter distances in Second Life is due not only to the fact that the area is smaller, but also to the fact that the interest of characters is focused in meeting other characters. There are no goals that may send a character to a remote point, which would lead to long distances. Their intention is to socialize with the other characters there, which are often at a short distance from each other. Once conversation begins, people tend to move less.

On the other hand, in WoW objectives are set in different points of the world, often apart from each other, like creatures to be challenged, caves to be explored and other places of interest, which almost often are located away from the cities. Thus, characters must travel long distances to reach those points of interest and also to return to the cities or their points of origin.

The CDFs of traveled distances show that more clearly, with a concentration of shorter distances for Second Life, with just about 10% of travels longer than 1000 meters. Considering the region is a square with sides 256 meters long, such traveled distances seem excessive in such limited space. We suspect most (or all) of those to be automated avatars (bots), which are somewhat common in Second Life — our crawler included. Next, if we consider WoW without teletransportation, about 50% of the characters traveled more than 1000 meters, and about 10% covered more than 20 kilometers. Finally, as should be expected, considering teletransportation increases distances significantly: more than 50% of the characters cover more than 10 kilometers in this case. That means that in this case the majority of the characters cover distances similar to or larger than those in the case without that capability, and less then 20% of the characters cover distances comparable to those found in Second Life. If we compare Second Life and WoW without teletransportation, approximately 50% of the characters in WoW still cover distances longer than all found in Second Life, largely due to the existence of mounts and other features in WoW that increase a characters mobility.

**Demographic Density.** To evaluate the occupation of the land in each world, we divided each region in squares with 20 meters on each side, and counted the total number of characters seen on each square during the 24 hours of our logs.

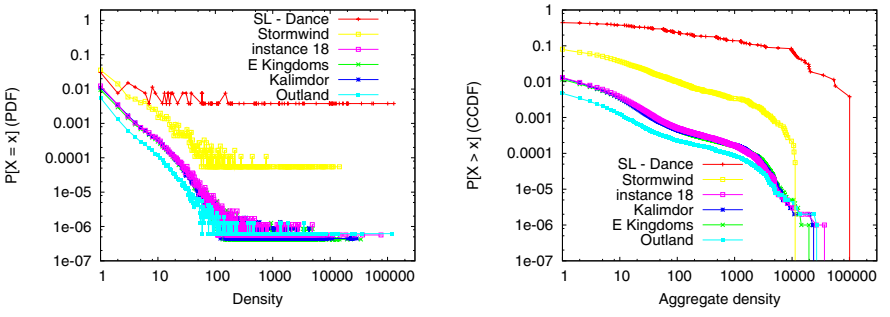


**Fig. 2.** Probability distribution, and complementary cumulative distribution of the aggregate demographic density

Figure 2 shows PDF and CCDF (complementary cumulative probability density function) of the aggregate density computed as the number of characters seen at each square. We can see that the PDF for Second Life stays constant for most of the densities, with some oscillation for lower concentrations. WoW, on the other hand, has a much more skewed distribution for all large areas, with a behavior close to a power law for most of the range considered. Stormwind, the city in Wow, being a restricted area, has a behavior closer to that of the Second Life land, although still closer to the general WoW pattern.

From the CCDF, we can see that the three continents and the instance in WoW, being larger areas, spent most of the day with no visitors (about 1% of the area had at least one visitor during the period, except for Outland, in which case less than 0.5% of the area was visited. Even in Second Life, more than 50% of the area was not visited according to the log. Again, the curve for the city, Stormwind, is closer to that of Second Life. It might be the case that they would be even closer if their areas were more close to each other.

### 5.2 Temporal Analysis

To better understand the nature of the interactions in each world, we considered the temporal dynamic of the contacts. The metrics used, time to first contact, contact time and inter-contact time, were discussed in Section 4.

Considering the strictly social nature of Second Live, time to first contact and inter-contact times should be shorter and contact time should be longer than for WoW. Second Life users enter the world mostly to socialize, so they seek other people as soon as they get on-line, reducing time to first contact. For the same reason, after they meet a character or a group, they tend to start a conversation in stead of just pass by and go somewhere else. That should be particularly true for Dance Island. As Table 2 and Figure 3 show, that is exactly the case, except in a few cases.

Stormwind, being a city, again shares some of the characteristics of Second Life. Cities serve as temporary bases and support facilities, so people tend to

**Table 2.** Contacts temporal metrics (averages in seconds)

| | | WoW | | | | | S.L. |
|---|---|---|---|---|---|---|---|
| | | E. K. | Kal. | Inst. 18 | Outland | S.W. | |
| Avg | First contact | 2170 | 1943 | 2695 | 520 | 195 | 163 |
| | Contact time | 89 | 170 | 316 | 128 | 474 | 284 |
| | Inter-contact time | 384 | 405 | 435 | 112 | 1222 | 387 |

seek populated places, like markets, banks and training sites once they reach them, leading to early contacts, so they have similar times to first contact. In the city, however, long sessions where players seek to improve their user experience (trading, grouping, training skills, seeking quests, chatting) seems to dominate contact times, making them even longer than for Second Life. Also, after characters part in Stormwind, they take much longer to meet again (if they ever do), as the average inter-contact time indicates. That was mostly due to the nature of the game: once characters part after training or conducting business they tend to leave the city for new quests, returning much later. Both features are also visible in Fig. 3, where we can see that approximately 50% of the inter-contact times in Stormwind are longer than 100 seconds, against only 30% in Second Life, and also the longer contact times for Stormwind (roughly 5% are longer than 2.5 hours).

Other elements of interest in Table 2 are the lower inter-contact time for Outland and high first-contact times and longer contact times in the Instance18. Those are also explained by the nature of the game. Outland is a continent visited by advanced characters in their quest to improve their rankings even further. In that condition, collaboration with other characters is important and they tend to meet often to exchange information, if for nothing else. That reduces inter-contact time. Instances are mostly places were collaborative game play is essential. Characters usually join outside an instance and enter them together. Once inside, they proceed together (getting closer or farther apart as the situation requires) but with no contacts with characters other than those in their group. We only registered the (eventual) moments when characters get more separated and then get closer again. On the other hand, contact times and inter-contact times capture the together-again-apart-again nature of the action.

From Fig. 3 we see that Second Life has fewer short-lived contacts: characters tend to at least try to start a conversation each time they meet, so contacts tend to last at least a little longer (only 20% last less then 30 seconds). On the other hand, in WoW is more common for characters to just pass by others while en route to a farther destination, without ever stopping — although that is, again, a little less common for Outland and Stormwind, for the reasons discussed. In both, there are some short-lived contacts but also some long-lived ones.

We can see basically five categories in terms of time to first contact in Fig. 3. Clearly Second Life is the one with lower values (almost 80% of the first contacts happen in less than 8 seconds, while the opposite is true for instance 18 (50% take longer than 4 minutes). Outland and Stormwind, since they have conditions

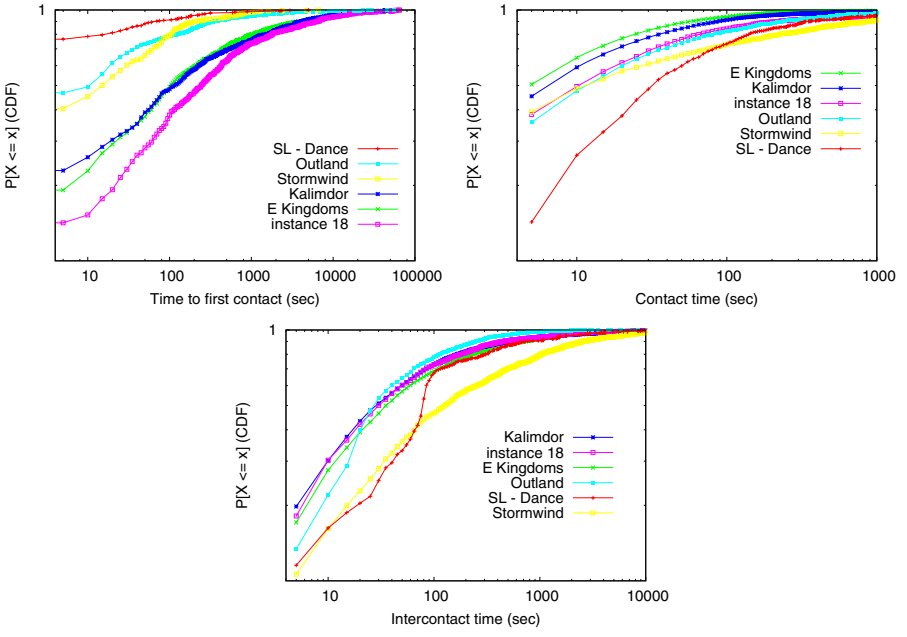


**Fig. 3.** Aggregate probability distributions for times to first contact, contact time and inter-contact time, respectively

that foster exchanges, have the lowest times to first contact in WoW (at least 50% are lower than 10 seconds in both cases), and finally Easter Kingdoms and Kalimdor, being continents with less advanced players, who tend to stay alone for longer periods, have higher times to first contact (approximately 50% are above 2 minutes).

## 6 Network Structures

Our goal in this Section is to understand the contact network formed by characters in the two worlds, based on the definition of contact as a function of physical proximity in the virtual world. This information is important to understand the opportunities for interaction in the virtual world, but also as a basis for the analysis of other events in the real world, like in the study of epidemics, or forwarding of messages in a mobile environment, for example.

Based on the logged information about character position in WoW and Second Life, we built a non-directional contact network, connecting characters who were closer than 10 meters from each other. For the degree analysis, only that, we considered the case where edges were all equal (there was any contact) and the case where they were weighted by the number of encounters observed between the two vertices they connect. That way, node degrees computed without weights give us the number of other characters each character was ever in contact, and

weighted degrees give us the total number of contacts each character had. For the graph without weights, we computed clustering coefficients, degrees, and betweeness for the vertices, as well as all pairs shortest paths.

The degree of each vertex shows the number of other characters a given character contacted during the duration of the logs. The weighted degree (sum of the values of a node's edges) tell us how many times that character had contacts. The clustering coefficient describes the probability of characters $B$ and $C$ meeting each other, given that another character $A$ had contacts with each of them. The shortest path indicates the minimum number of characters that would have to be contacted to relay an information from $A$ to $B$, and the betweeness represents the probability of a certain character being in the shortest path between any pair of vertices. These metrics help us understand how contacts (and possible interactions) happen between characters in a given virtual world, and allow us to estimate how closely nit are groups, how separate can communities be, and whether some characters may play a major role in the exchange of information and goods between the population of the virtual worlds. Average values for those metrics are shown in Table 3.

Clearly, Second Life and the Stormwind city have the highest degrees among the regions considered, although Stormwind's are noticeably higher, what may be explained by the larger number of characters which visited the city when compared to the number of visitors to the Second Life island during the time of the measurements. The average number of contacts in instance 18 is lower due to the nature of the game, since groups enter the area and stay close for the time it take them to complete the task they are there to complete. In Kalimdor and Eastern Kingdoms, although the average number of characters contacted is lower, contacts tend to repeat more often (averaging three contacts per pair, against two in other realms).

For a more detailed analysis, Figure 4 shows the probability distributions for node degrees and weighed degrees, while Figure 5 show the cumulative probability distributions for the same values for each contact network. It is noticeable that vertex degrees in both WoW and Second Life match power laws. That means most of the vertices have low degrees, but a small fraction of them have very high degrees. Characters in both Second Life and Stormwind have lower probability of having smaller degrees and higher probabilities of having higher degrees than the others. The results for weighted degree are similar and curves follow similar patterns.

**Table 3.** Average values for the contact network metrics

| | | WoW | | | | | S.L. |
|---|---|---|---|---|---|---|---|
| | | E. K. | Kal. | Inst. 18 | Outland | S.W. | |
| Averages | Degree | 13 | 12 | 6 | 14 | 37 | 16 |
| | Weighted Degree | 36 | 35 | 12 | 22 | 69 | 24 |
| | CC | 0.31 | 0.32 | 0.35 | 0.55 | 0.50 | 0.50 |
| | Betweenness | 0.0038 | 0.0041 | 0.0059 | 0.0031 | 0.0035 | 0.0061 |
| | Shortest Path | 4.5 | 4.0 | 5.4 | 5.6 | 2.3 | 3.6 |

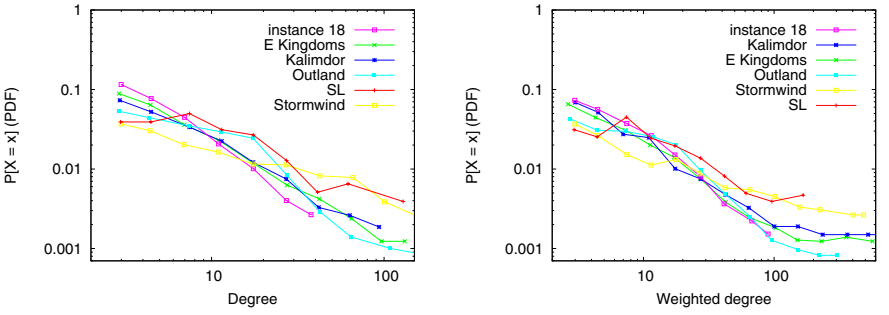


**Fig. 4.** Degrees and weighted degrees for the contact networks (PDF)

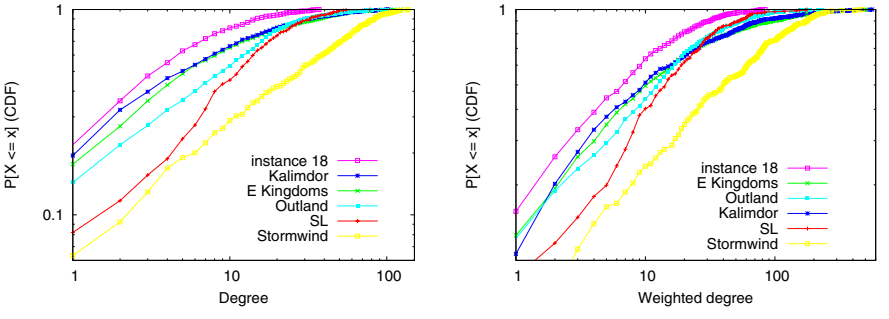


**Fig. 5.** Degrees and weighted degrees for the contact networks (CDF)

The cumulative distribution of degrees and weighted degrees (Figure 5) confirm the tendency of the collaborative areas (Second Life island and Stormwind city) to foster more character contacts. The probability of characters with few contacts are much lower in those areas (less than 8% of the characters have no contacts while in there, against at least 15% for the others). However, Second Life has fewer nodes with a very high number of contacts (only 10% have contacts with more than 30 characters, against more than 40% in Stormwind). Results are similar for weighted degrees.

As seen in Figure 6, clustering coefficients (CC) are more highly concentrated in Second Life and Stormwind. Only 20% of the nodes have CC lower than 0.2 and 0.3, respectively, and the curves get more similar for larger values. On the other hand, approximately 20% of the nodes have CC higher than 0.6. The two continents other than Outland and the instance have lower CC values overall. Outland, the continent for more advanced characters, although showing a higher probability of low CCs than Second Life and Stormwind (40% of the nodes have CC smaller then 0.3), it has a higher concentration of larger values than those realms (20% have CC larger than 0.8). That may have a relation to the fact that interaction is more important in higher levels of the game and some characters get a lot of clustering.

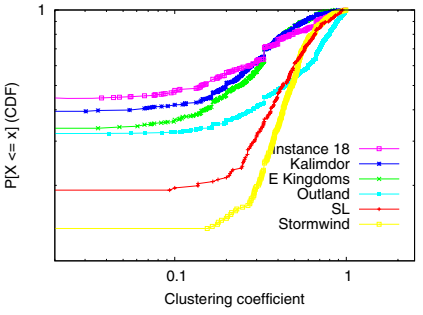


**Fig. 6.** Clustering coefficients for the contact networks (CDF)

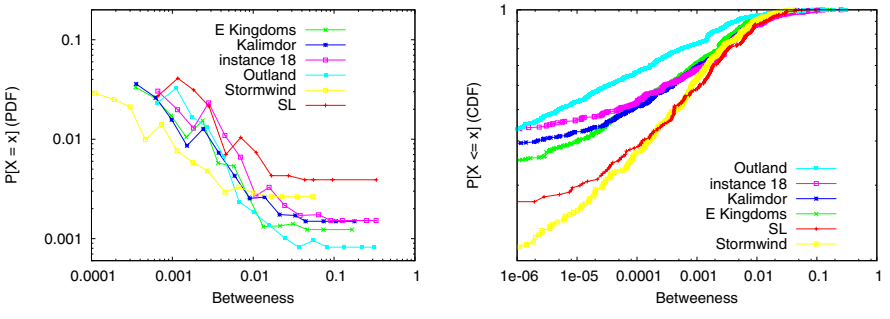


**Fig. 7.** Betweeness: probability distribution and its cumulative distribution

The probability distribution for betweeness is shown in Figure 7. Based on that value we can evaluate the structure of the underlying graphs. Graphs with strong hierarchical structures, or with clusters connected by one or a few links, named bridges, tend to show a highly uneven distribution of betweeness. That is the case because most of the paths go through those central links, while on a less hierarchical graph, or one with fewer bridges, paths will go through more nodes, leading to less uneven distribution. Apparently, for the contact networks of the virtual worlds considered, although there are a few characters that contacted a large number of others, in general the networks have low betweeness. For example, for Easter Kingdoms, 99.5% of the characters have betweeness under 0.07. However, three characters have a much higher value, around 0.16, meaning that 16% of the shortest paths go through them. That suggests the existence of bridges or similar structures in those contact networks.

On the other hand, for Second Life and Stormwind there are fewer very low values, so the distribution of paths is less skewed, suggesting a less hierarchical structure. On the other extreme, Outland, the realm of more advanced players, has mostly low values for that metric (more than 70% of the nodes are in at most 0.1% of the paths, and only 10% of the nodes are in at least 1% of the paths. It may be the case that when all characters are at a higher level and all

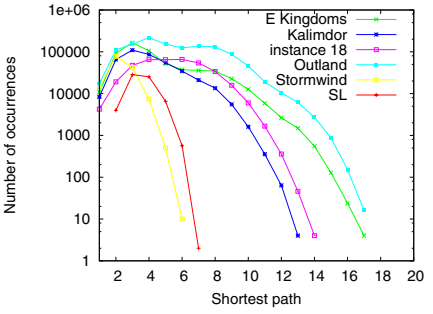


**Fig. 8.** Histogram of shortest paths values observed for each region

seeking the same goal they tend to avoid situations where many of them may depend on a few others.

The distribution of shortest path distances is an interesting metric for the characterization of complex networks, since it reveals the network diameter. It shows the intensity of the interactions on the network and suggest how fast information (or resources) can travel from one point of the network to another one. Observing Figure 8, the histogram of the shortest path distances found for each realm, we can see that both Second Life and Stormwind follow similar patterns with lower maximum distances. That is expected, for environments where the interaction is the major goal of its occupants. On the other hand, advanced players tend to build networks with larger diameters, as seen in the case of Outland and even the other WoW realms. That may be an indication of the impact of competition, which is always a factor in those areas.

## 7 Conclusions

We have observed World of Warcraft and Second Life, characterizing them in terms of the spatial and temporal nature of the contacts between user-controlled characters and of the network built from contact events. The two worlds showed significant differences in terms of the distances traversed by characters, but more similar patterns in terms of density of occupation of the areas.

In terms of distances traveled, we concluded that differences are mostly due to the fact that regions in WoW are usually larger, and also to the fact that the nature of the game leads characters to seek their goals in remote locations of the territories. In Second Life and the WoW city considered, characters tend to stay in areas which are smaller and more highly populated, traveling less. In all cases, most of the area is empty most of the time, while some regions attract more attention from players.

In the temporal analysis of contacts we have observed the influence of the nature of the game: time to first contact is shorter in Second Life, a purely social game, than in WoW, where players have various goals, many of them not requiring contact with others. Also in this case, Second Life is closer to

Stormwind city, although with still shorter times. Contact times are longer in Second Life on average, since in search for socialization people tend to spend time together, although some times were longer in Stormwind due to the nature of some contacts there. Inter-contact times in Second Life were shorter, since socialization again draw characters together more often.

In the study of the network of contacts, differences were more noticeable between realms associated with different objectives than between the two virtual worlds as a whole. The differences in clustering coefficient are explained by the fact that people tend to interact more as groups in Second Life, but also in Stormwind, to some extent. On the other hand, when cooperation was more necessary in the area for advanced players in WoW, we also found higher clustering coefficients. However, while the betweeness in openly competitive areas showed the formation of some structure, that was less noticeable in the social areas (although still present) and even less so in the highly competitive realm of advanced players where they tended not to rely on other characters as much, although interactions were common.

In conclusion, we have observed that the similarities and differences in the way characters get in contact with each other in the virtual worlds of Second Life and World of Warcraft, for the cases considered here, are more dependent on the nature of the interaction expected in each area than on the particular virtual world they take place. In that aspect, the Second Life Island and the WoW city, where cooperation between characters was the major objective, were often more similar to each other than the city to the rest of the WoW world, where competition played a major part. Not only that, but the nature of the goals of characters in each area also set them apart. The continents open to all players were clearly similar to each other, while the continent restricted to more advanced players and the instance dedicated to special group play had particular elements explained by their nature.

We intend to further our analysis of these findings in our future work, using more detailed information from the WoW logs to better qualify each interaction between characters, so we can more clearly identify the effects of cooperation, competition between members of a same group with conflicting goals and open competition, forced by the nature of the game, between rival factions. We also intend to apply the information about mobility patterns and contacts to the study of epidemics, both in the case of biological threads (diseases) and computer related (malware dissemination in wireless networks).

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