Instant Messaging as a Scale-Free Network

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The topology of an instant messaging system is described. Statistical measures of the network are given and compared with the statistics of a comparable random graph. The scale-free character of the network is examined and implications are given for the structure of social networks and instant messenger security.

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I. INTRODUCTION

The last few years has seen a large advance in our understanding of networks whose structures are by nature non-equilibrium and non-random. These networks have been used to study systems as diverse as the Internet router and WWW hyperlink networks, electric power grids, and cellular metabolic pathways [1, 2]. In particular, these networks prominently feature a power-law frequency distribution for the nodes’ degree (scale-free network), a network diameter smaller than a comparable random graph, one with the same amount of nodes and the same average degree per node, and a much larger clustering coefficient than a comparable random graph.

Among the most interesting of the networks studied are those that analyze human social interaction. The phenomenon of six-degrees of separation, first recognized by Stanley Milgram [3], is well known and documented in both academic and popular culture. The most detailed of these networks studied are actor collaboration networks and scientific collaboration networks [4, 5, 6, 7]. Interestingly, the web of human sexual partners have also been documented [8]. Typically these networks share the features mentioned above that differentiate them from random graphs and display a scale-free character. This paper hopes to add to these studies on social contact networks by adding another example: the connections of users in an instant messaging service.

II. OVERVIEW

Instant messaging has grown at a phenomenal rate in the last several years to become a major form of communication both over the internet and within company intranets. Instant messaging has become so important in fact that the FCC has attempted to force the largest server for instant messaging, AOL Time-Warner, to open its software for interoperability [9].

Instant messaging is distinguished from regular chat as being a one-on-one conversation between two users on an instant messaging network. Typically in instant messaging systems each user has a user name and a contact list containing the user names of other users who they often communicate with. It is this feature of instant messaging that makes it amenable to scientific study and statistical analysis. If one imagines each user as a node and each contact on their user’s contact list as an out-directed edge, the community on an instant messaging network can be modeled using graph theory.

Using these assumptions it can be easily seen that an instant messaging network represents a non-equilibrium graph in that nodes (users) are added and removed over time and edges most likely accumulate on users in a non-random fashion. One possible model for this growth is the Barabási-Albert (BA) model where edges are formed by preferential attachment. Those nodes with more edges are more likely to accumulate edges as time goes on. Similarly one could hypothesize a user is more likely to form out-directed edges (add users to the user’s contact list) the more users are already present on their contact list and a user is more likely to receive in-directed edges (being on another user’s contact list) in a similar fashion.

With these assumptions an instant messaging network’s graph should probably display a scale-free character. To test this hypothesis an instant messaging network using the open-source Jabber protocol was researched to find such features.

A. The Jabber Instant Messaging Protocol

To clearly understand some of the assumptions and conclusions in this paper a cursory overview of the Jabber protocol is necessary [10]. The Jabber protocol is based off of XML and uses a distributed client-server architecture. Jabber was consciously based off of the architecture of email systems so instead of one central server like AOL’s Instant Messenger or Microsoft’s MSN Messenger, Jabber has many servers in many locations. Jabber clients are the users who communicate with instant messaging. Clients can communicate with all other...
clients on their Jabber servers and with clients on other Jabber servers since the Jabber servers can communicate with each other. In addition Jabber supports additions called transports that allow Jabber clients to communicate with clients using other protocols such as those on AOL, Microsoft, ICQ, or Yahoo instant messaging.

III. NETWORK STATISTICS

The network studied was the instant messaging database from nioki.com, a French language teen-oriented web site. Appropriate measures were taken to completely preserve the anonymity and privacy of the users as is explained in detail in Appendix A. The nioki.com database contained 50,158 users (nodes) with almost 500,000 edges. Due to the model explained earlier, this instant messaging network was modeled as a directed graph. This is different from other social network studies such as the actor-movie collaboration network which was modeled as a bipartite graph and the scientific collaborations which were modeled as undirected graphs.

The nioki.com instant messaging network was found to exhibit all the characteristics of a scale-free network. The inward and outward directed edge frequency distributions both followed power laws with a $\gamma_{in} = 2.2$ and $\gamma_{out} = 2.4$. The average in and out degrees are $\langle k_{in} \rangle = 9.1$ and $\langle k_{out} \rangle = 8.2$. The average in and out degrees are identical in a network with no outside contacts. However, as explained in the description of Jabber, clients have the ability to communicate with clients on other servers outside their current server. So there are probably contacts with clients that are not on nioki.com’s server. The data does not indicate who these contacts are but the difference in the average in and out degrees per node intimate their existence. The diameter of the network, $\bar{\ell} = 4.35$ so that there are about 4-5 users on average between any two users on the network. These values indicate the small world character of the nioki.com network as compared to a random graph (Table I).

Since this network is modeled as a directed graph, it presents a rather asymmetric view of human social interaction. In a directed graph it is possible for one user to "know" another without the other user reciprocally expressing such a relationship. This is because the contact list data we have does not require a reciprocal relationship between two users. Measurements indicate about 82% of the contacts in the network are in both directions. So on average 82% of the users on a given user’s (user A) contact list also have the user A on their contact list. In order to get a clearer view and calculate the clustering coefficient, a new list of users and contacts was created adding those edges necessary to make the network undirected. In this case the power exponent of the degree distribution became $\gamma = 1.8$. The average degree was $\langle k \rangle = 9.6$ and the diameter of the network decreased to $\bar{\ell} = 4.1$. The average clustering coefficient was calculated at $\bar{C} = 0.33$ further reinforcing the small-world character of the network.

The final measures computed were the size of the giant weakly connecting connected component (GWCC) and the giant strongly connected component (GSCC). The GWCC is the number of nodes on the network that can be reached by any other node in the component ignoring the directions of edges. It was calculated at a very large 49,801 users or over 99% of the users on nioki.com. Only about 0.7% of the users were in disconnected components. The GSCC is a measure of the number of nodes in the component where any node can be reached from any other node through directed edges. This was calculated to be 44,581 or 89% of nioki.com’s users. These very large values for the connected components are probably most likely explained by the structure of the nioki.com website itself. It is mostly made up of users who communicate using the nioki instant messaging service with other users on nioki.com. It is unlikely that nioki.com’s instant messenger is used as a primary instant messaging tool for users on other servers or services by most users. Being a teen oriented website geared toward socialization it likely has a tightly knit community over shared interests. This is unlike the actor or scientific collaboration databases where communication is mainly limited to professional roles and fields of research.

IV. CALCULATIONS OF RANDOM GRAPH ATTRIBUTES

The random graphs statistics in Table I were computed using the following equations which are theoretically explained in detail in Appendix A. The comparable random graph was assumed to have the same number of nodes and average degree per node as the undirected model of the instant messenger network. From this information the average clustering coefficient of the random graph can be calculated as

$$\bar{C} = \frac{\langle k \rangle}{N}$$

(1)

It is interesting to note that the clustering coefficient of a random graph is the same as the node connection probability. The shortest path was estimated using the approximation

$$\bar{\ell} = \frac{ln(N)}{ln(\langle k \rangle)}$$

(2)
V. COMPARISONS WITH BARABÁSI-ALBERT MODEL

Earlier, the possibility that this network grows according to the Barabási-Albert model was considered. A key indication of this would be a measure of the preferential attachment probability $\Pi(k)$. Though the empirical data from the network and its scale-free character hint strongly towards the Barabási-Albert model or a comparable one, time dependent data was not available to allow the determination of the shape (linear or curved) or function of $\Pi(k)$.

VI. RELEVANCE TO SOCIAL NETWORKS

A frequent question with the ever faster globalization and communication in the world is how connected we all really are. This research covered a relatively large sample of about 50,000 people and in some ways gives a glimpse into the connectivity of our society, but in other ways falls short.

This research should give additional credence to the growing evidence of the scale-free nature of social and professional contacts in greater society. Combined with the earlier studies on professional collaborations it seems to indicate that society does exhibit a "small world" effect. This research finds that the small world of nioki.com is based on a scale-free topology, however, there are other models of small worlds including the Watts-Strogatz model which exhibit similar features. The small diameter compared to the number of nodes in the network indicates that the degrees of separation in nioki.com are a bit smaller than the six Stanley Milgram measured in his studies. However, there are caveats to the wholesale application of these results to larger society. Nioki.com is probably more connected than society at large due to its foundation of shared interests and demographics (young adults). The large size of the GWCC and GSCC is an indication of this. Thus, the researcher does not think it would be completely accurate to say everyone in the world is connected by 4-5 people. In fact in a recent criticism of Milgram’s work[11], it is asserted that studies that do not take into account the increased likelihood of connections based on factors such as demographics or professional affiliation may not clearly represent the larger society. Though I believe this research further emphasizes that human social networks have a small world character, this research cannot address the question of the connectivity across varying demographics or social boundaries.

VII. APPLICATIONS TO INSTANT MESSAGING SECURITY

In instant messaging, like all computer network communications tools, security is often a paramount consideration. Though there are many problems of interest in the security of instant messaging from the privacy of conversations to the security of user accounts and passwords the aspect of security most pertinent here is the spread of worms across instant messenger networks. There have been several recent outbreaks of worms on instant messaging networks [12]. The spread of epidemics on scale-free and small world networks has been well studied. It is known that there is no epidemic threshold for infinitely
large scale-free networks [13, 14] and worms or viruses can spread rapidly through a network. Though there have not been any devastating worms so far it is wise to prepare to interdict the worst possibility. Let us assume a worm spreads through an instant messaging network by infecting a node and then spreading itself along all or some of the out-directed edges to new nodes which also may be infected. This is similar to recent worms which send a message containing an infected link to all members of a user’s contact list. The dynamics of this kind of epidemic have been discussed [13, 14, 15]. However, the options for stopping or slowing the epidemic are varied. You can alert users or provide a patch or software to prevent the spread as was done with the Code Red virus that infected Windows 2000 servers [16]. With a more extreme event, however, more radical measures could be necessary.

Unlike the Internet, where control is decentralized, the client-server nature of instant messaging makes more radical measures possible. Research has indicated that scale-free networks though they are robust to random node failures, are very vulnerable to attack [17, 18, 19]. A directed attack at the most connected nodes could severely damage a network such as the Internet. However, this characteristic could be reversed and turned to an advantage in halting an epidemic [14, 20]. In a severe instant messaging worm outbreak the server administrators could slow, but not completely stop, the spread of a worm in a way that does not affect the service for many users. By disabling the accounts of the most connected users on the network, they could effectively increase the network’s diameter making the propagation of the epidemic much slower and buying time for a patch or another curative measure. The diameter of the nioki.com network after a certain percentage of the most connected sites are removed is shown in Figure 4. Removing the top 10% connected users increases the diameter of the network almost twofold. However, even disabling up to 10% of the most connected users would leave connectivity for the other 90% of the network and allow the service to have more time to cope with the outbreak and help other users. There are caveats to this plan, however. This would only work assuming that the most connected users are online frequently enough to spread the worm. If many of the most connected users are rarely online, this strategy may not produce its full effect. Also, this strategy would still deny a segment of users usage to the network for an unspecified period of time and would possibly upset many users if it is used too frequently.

VIII. CONCLUSION

In this paper the network structure of the instant messaging community of nioki.com was investigated and demonstrated to be a scale-free network. Though the preferential attachment was not determined, it is likely that the Barabási-Albert or similar model describes its evolution. Knowledge of this structure may tell us more about social networks in the real world and how to prevent the spread of worms on instant messaging networks.

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APPENDIX A: NIOKI.COM USER PRIVACY CONSIDERATIONS

Of the utmost importance was protecting the privacy of the users of the nioki.com instant messaging network that was researched. Here all privacy precautions taken are outlined and explained in detail.

The data received by the researcher of this paper was in the most raw form possible. The data from nioki.com was prepared so that all users and their contacts were anonymized as numbers. Users and their contacts were then matched up by matching a user number with a contact number. The researcher did not receive any user names, emails, IP addresses, geographical locations, personal information or activity information, or any other data that could allow him to either determine the identity of any given user or extrapolate anything about a user’s activity on nioki.com or the Internet at large. It would have been impossible for the researcher to determine any direct personal information or identity about anyone from this raw data.

The data was only in the hands of the researcher at all times and was not given to any collaborators, published publicly or distributed in raw form, or sold for profit. The data was statistically analyzed in aggregate and therefore no information about any specific users could be extrapolated. A rough metaphor of this experiment would be analyzing census data for a town. Aggregate patterns will emerge but no specific information about individual inhabitants can be gleaned from the data. In order to further protect privacy, this researcher cannot distribute the raw data to any others interested, even for research purposes. Such requests must be made directly to nioki.com.

If there are any other questions or considerations regarding the privacy of this research, please direct them to the email at the top of the paper.