Scale-free application layer implementation for ad hoc networks

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***Abstract* — The groups of people that use a communication network are a part of some kind of social network. In order to be able to simulate the real life usage of communication networks for human information sharing, in this paper a scale-free application layer, based on social networks properties, is proposed. The simulations show that the social interconnection between the network users has a significant influence on the network performances. The results bring forth a different view on the real life deployment of ad hoc networks when compared to the poor performances of the purely randomized scenarios.**

***Keywords* — ad hoc networks, application layer, scale-free, social networks.**

I. Introduction

THE view that complex networks are random, held for decades under the influence of Erdos and Renyi, has lately been questioned on many fronts. Their eight papers [1] laid down the foundation of the theory of random networks: by deliberately discarding the fact that different systems follow disparate rules in building their own networks, they follow the simplest solution - connect the nodes randomly.

However, this simple view of the complex network was shattered when the 'six degrees of separation' paradigm [2] was introduced suggesting that, despite the enormous size, real complex networks can easily be navigated due to their high clustering coefficient and, yet, small average path length, which was never the case with random graphs. Thus, with society being a very dense complex net, we live in a small world. To explain the ubiquity of clustering in most real networks, Watts and Strogatz [3] offer the "small world" alternative to the random network model. The model offered an elegant compromise between the completely random world, which is small world but hostile to circles of friends, and a regular lattice, which displays high clustering but in which the nodes are far from each other.

The small world phenomena and its influence on the performances of ad hoc networks was investigated in [7],[8] and [9] using the specially defined small world application layer in [6].

After the small world breakthrough, a new revelation occurred. Malcolm Gladwell's [4] conclusion from the test of the amount of sociability has shown an altogether new property of social networks: hubs –nodes with an anomalously large number of links – are present in very diverse complex systems, ranging from the Internet to the cell.

The problem with the egalitarian model of Erdos and Renyi is that hubs are extremely rare. The Watts-Strogatz model also forbids nodes with significantly more links than the average node has. This is why, when hubs were discovered in many real networks, a new, scale-free, model of complex networks emerged. The small world property and the appearance of hubs are sublimed into the scale-free network model.

The people that use some sort of communication network in order to share information are also part of some social network. Since most human communication takes place directly between individuals, social networks have crucial importance when investigating communications. This viewpoint clearly shows that in order to know how the communication network is going to be used in practice we have to observe the properties of the social network of its users.

Therefore, in this paper, we discuss the implementation of a scale-free application layer for communication networks. Using this layer, we'll be able to observe the real pattern of communication in the network we are investigating. The results given in this paper are for the case of ad hoc networks, since the social influence of the individual that is carrying the wireless ad hoc device is the at its highest for this type of networks.

The remainder of this paper is organized as follows. In Section 2, we bring forward the ways of modeling scale-free networks. Section 3 shows the way we model our scale-free application layer and its implementation in the NS-2 network simulator. In Section 4 the obtained results for the case of ad hoc communication network are presented and in Section 5 conclusions are presented.

II. Scale-free networks

Hubs dominate the structure of all networks in which they are present, making them look like small worlds. Indeed, with links to an unusually large number of nodes, hubs create short paths between any two nodes in the

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system. This fact is mathematically formulated with the power law degree distribution.

While observing the hubs, two essential network properties were disclosed: first, despite their diversity most real networks share an essential feature, growth. Second, in real networks linking is never random. Instead, popularity is attractive.

Putting the pieces together, Barabasi and Albert [10] have shown that real networks are governed by two laws: growth and preferential attachment.

They also propose an algorithm (SF algorithm 1) [11] for modeling a scale-free network which incorporates both laws:

a) Growth – for each given period of time we add a new node to the network.

b) Preferential attachment – each node connects to the existing nodes. The probability that it will choose a given node is proportional to the number of links the chosen node has, $k \Big/ \sum_i k_i$.

According to this Basic Model each network starts from a small nucleus and expands with the addition of new nodes. Then these nodes, when deciding where to link, prefer the nodes that have more links. This rich-get-richer phenomenon naturally leads to the power laws observed in real networks.

After the first model appears making it possible to create a scale-free network using growth and preferential attachment, several additions to the model follow.

The "new kid on the block" effect also appears to be present in most networks. In most complex systems each node has fitness, intrinsic qualities that influence the rate at which they acquire links in a competitive environment. Fitness, η, is a quantitative measurement of a node's ability to stay in front of the competition.

The Fitness Model is an extension of the basic model that incorporates this behavior. According to this algorithm (SF algorithm 2) [11], preferential attachment is driven by the product of the node's fitness and the number of links it has. Each node decides where to link by comparing the fitness connectivity product, $k\eta \Big/ \sum_i k_i \eta_i$, of all available nodes and linking with a higher probability to those that have a higher product and therefore are more attractive.

An interesting variation of this model is the so-called Life Model which takes into account the fact that old nodes eventually stop grabbing new links. According to this algorithm (SF algorithm 3) [12], every node has a limited period of time of being fit to grab new links. After this time expires the node can no longer obtain new links.

III. SCALE-FREE APLLICATION LAYER

Since who is communicating with whom is completely up to the network user, the application layer is the place where the influence of the user interconnectivity rises to its full extent. Of course, the chances that a group of complete strangers got together to communicate and share information are not questionable. Thus, we can freely expect to see an overlap between the strength of the social ties of the users and their communication network usage pattern. Each user is going to send and receive information to and from his friends.

In order to be able to generate a realistic scale-free application layer with the above mentioned characteristics, we need to create a scale-free network that maps the links between the network users. For these purposes, we created a module for generation of a scale-free network which uses one of the three algorithms for the scale-free network formation:

1) Basic Barabasi-Albert Model,
2) Fitness Model,
3) Life Model.

The scale-free network generation module that creates the network is based on several input parameters: number of users, number of acquaintances for each new node in the network. Also, for the SF algorithm 2, fitness is assigned to each node randomly. The same is done for the life values in SF algorithm 3, where the values are randomly assigned in the [0, maxlife] interval.

The result from this module is a social connectivity matrix, with size N x N, where N is the number of users. This matrix is basically the definition for the possible end-to-end connections for the data packets in the network.

Using the connectivity matrix, the application layer for each node knows its friend-nodes in the network. So, when the application layer creates data packets, they must have a destination address of a friend node of the source. In other words, a node can not send data to a non-friend node, which is a realistic property of the way humans use the communication networks. Every time when the node generates a new data packet it randomly chooses a friend for a destination of the packet.

With the scale-free application layer, a scale-free traffic generator is also designed in order to control the packet generation during the simulation time, so we can easily change the network load creating traffic with different properties. Input parameters for the traffic generator are: number of network users, offered load in Mbps, number of simultaneous messages, simulation time and message size. The generator randomly chooses the source nodes and the moments of packet generation in order to create the desired traffic in the network.

A. Implementation in the NS-2 network simulator

Both, the scale-free application layer and the traffic generator were implemented as an extension of the well known NS-2 network simulator, since this simulator is one of the most widely accepted and accurate simulators for research of different wired and wireless networks [13].

A new type of application layer, SF_App, was added in the simulator, thus making the node aware of the social life of the user it represents. The goal of the scale-free application layer is to provide end-to-end communication between the socially connected nodes.

SF_App has a record of all friends of the host. When a node wants to communicate with one of its friends, the layer creates a connection with the friend and sends him a SF_MsgString message. In order to be able to dynamically change the state of the social network during simulation time, SF_App allows adding or deleting a friend from the list of friends of the host. In this way, we can use SF_App for simulations with long simulation time while adapting to the social network changes that appear during the different periods of the users activity (for example, while at work he is communicating with its colleagues, and while at home with its family).

B. *ScaleFreeApp tool for ad hoc networks*

Ad hoc networks are communication networks designed especially for the moments when people come together and need to establish a network on the fly in order to aid them in their communication. An example of potential applications of mobile ad hoc networks is a group of people with laptop computers at a conference that wish to exchange files and data without mediation of any additional infrastructure.

Since the communication in the ad hoc network is under deep influence of its users and their social links, we decided to measure the effect the scale-free phenomena of the ad hoc users social network has on the ad hoc network performances.

For these purposes, we also created an additional tool that generates scale-free simulation scripts for the NS-2 simulator. The ScaleFreeApp tool is based on the SF_App layer and its input parameters are:

- Number of network users
- Algorithm for scale-free network generation
  - SF algorithm 1, 2 or 3
- Number of acquaintances for each new node in the scale-free network
- Offered load in Mbps
- Data packet size
- Simulation time

Firstly, ScaleFreeApp generates the connectivity matrix according to the chosen algorithm. Afterwards, based on this matrix, it generates a tcl script wherein it creates the ad hoc nodes and attaches scale-free application layer for each node in the network providing information for the friends of each node. In the second part of the script follow the details for the traffic in the network.

The last step is definition of the physical positioning of the ad hoc network nodes. The nodes are uniformly scattered in the network area and they are moving according to the Random Direction movement model [14] with a predefined average speed.

The tool also allows exclusion of the scale-free application layer and use of a completely random communication pattern, which is done in order to provide replicable conditions for the ad hoc network which allow us to be able to compare the performances with and without the SF_App.

IV. PERFORMANCE RESULTS

A. *Scenario characteristics*

In the simulations, 100 nodes are placed in a square-shaped area of 1km x 1km. The nodes are randomly scattered in the whole area, and are free to move across the whole simulation area with an average speed of 1m/s and 0.01 standard deviation.

At the physical layer, a radio propagation model supporting propagation delay, omni-directional antennas, and a shared media network interface are used. The IEEE 802.11 Medium Access Protocol is employed at the Link Layer level and the transmission range is set to 250m. AODV routing protocol [15] in combination with UDP are used.

All scenarios are tested with offered load from 0.1Mbps to 7Mbps.

When using the scale-free application layer, the number of friends for each new node is 5, while for the SF algorithm 3 the maxlife parameter value is set to 100 time units.

In order to analyze the influence of the scale-free application layer, we make the same simulation using a random end-to-end communication. In the random traffic scenario, destination nodes are randomly chosen from the whole population of nodes, regardless of the social links defined in the scale-free social network.

B. *Performance metrics*

For ad hoc network performance measurements using the scale free application layer the following performance metrics are used: end-to-end throughput and scale-free performance factor. The end-to-end throughput represents the total amount of bits received by all nodes per second and is measured in bits per second (bps). In order to quantify the impact of the scale-free application layer on the performances of the ad hoc network we use the scale-free performance factor (SFPF) defined as the ratio of achieved end-to-end throughput with scale-free application layer and end-to-end throughput without it (random traffic on application layer).

C. *Simulation results*

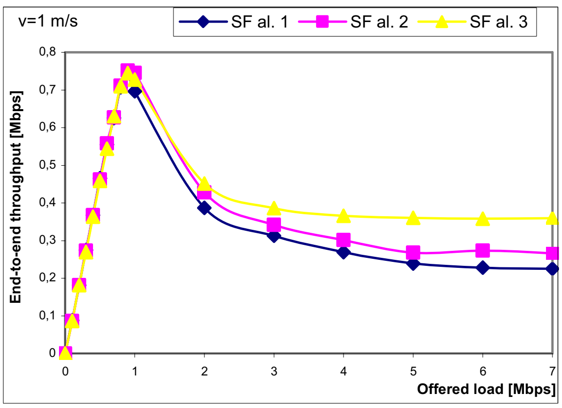

Fig. 1. Influence of the scale-free network generation algorithm on the ad hoc network performances

On Fig. 1 the ad hoc network performances are shown when using the three different algorithms for the generation of the scale-free social network. It can be seen that the basic model has the worst performances and is also under a great influence of the increasing load. Similar behavior shows the fitness model with slightly improved performances. However, the life model shows steadily increasing performances when compared to the other two, while being under a very slight influence of the increasing load in the network. This is due to the more even distribution of hubs throughout the social network.

Yet, it must be noted that the difference in performances is very small. When viewing the performances for light loads, up to 1 Mbps, the three models have almost identical performances.

In order to compare the obtained results with the results for a completely random scenario, the scale-free performance factor is shown on Fig. 2 for the different algorithms used to create the scale-free network. It is immediately evident that the performances of the scale-free ad hoc network are in average 3.5 times better than the random. The best results appear when using the life scale-free model, in which case the performances are up to 4.5 times higher.

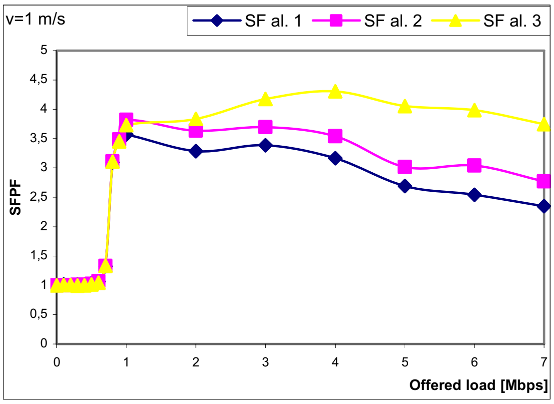

Fig. 2. Scale-free performance factor for different scale-free models

The reason for the higher performances lies in the fact that when friends are using the ad hoc network for communication there is no high variation in the source destination pairs. This is especially true for the hubs, since the probability that a hub will be source or a destination is very high. So after the first route discovery, the following packets are forwarded via the previously discovered route. When considering the random scenarios, because of the random nature of choice for source and destination, the chances that the same pair will be used several times is much lesser, so the network is loaded with many control packets.

V. Conclusion

The new views on the properties of social and other complex networks have clearly shown that small world and scale free networks show properties that largely differ from the random graphs. This is the main reason why the next step in the performance analysis of communication networks should be replacement of the random traffic generators on the application layer with a more realistic pattern which reflects the real life use of the network. In this way we will be able to gain some insights of the way the network will perform when used in real life conditions for different kind of uses. These insights can afterwards help to tune the network to the conditions of use.

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