Small world application layer for ad hoc networks

Conference Paper · January 2003

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XI TELEKOMUNIKACIONI FORUM TELFOR 2003, Beograd, Sava Centar, 25.-27.11.2003.g.

SMALL WORLD APPLICATION LAYER FOR AD HOC NETWORKS

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I INTRODUCTION

A mobile ad hoc network is an autonomous system of mobile entities connected by wireless links. Nodes in an ad hoc network can act as both hosts and routers given that they can both generate and forward packets. Since there is no existing communication infrastructure (e.g., a wired or a fixed wireless base station), all entities are free to move while creating a self-organizing dynamic network. Ad hoc networks are suited for use in situations where infrastructure is either not available, not trusted, or should not be relied on in times of emergency. A few examples include: military solders in the field; an infrastructure-less network of notebook computers in a conference or campus setting; the forestry or lumber industry; space exploration; undersea operations; and temporary offices such as campaign headquarters [1].

The people that come together and form an ad hoc network in order to share information are also part of some social network. Since most human communication takes place directly between individuals, such networks are crucially important for communications. This sociological concept is the basis for small world research, which describes the tendency for each entity in a large system to be separated from any other entity in the system by only a few steps [2].

Small world networks are promising candidates for communication networks since data-flow patterns show a large amount of clustering with a small number of "long-distance" communications that need to be accomplished efficiently [12]. This is a result of the fact that people tend not so much to have friends as to have groups of friends, each of which is like a little cluster based on shared experience, location, or interests (see Fig 1.). This groups are joined to each other by the overlaps created when individuals in one group also belong to other groups [3]. Most of the communication between the entities is done inside the friends cluster while the necessity to communicate with a non friend is scarcely rare.

In most of the articles on ad hoc network performances traffic in a randomly connected nodes environment is considered. Examples can be found in [4][5]0. Johansson et al. [7] made a performance analysis by simulating three realistic scenarios that include rescue operations in remote areas, ad-hoc networks between notebook computers used to spread and share information among the participants of a conference; and short range ad-hoc network intercommunication of various mobile devices (e.g., a cellular phone or PDA). For the purposes of investigating the performances of ad hoc networks in [8] an application layer with clustering is used and in [9] the effects of small world phenomena on performances of ad hoc networks is performed.

In this paper we propose a new realistic model for application layer in ad hoc networks.

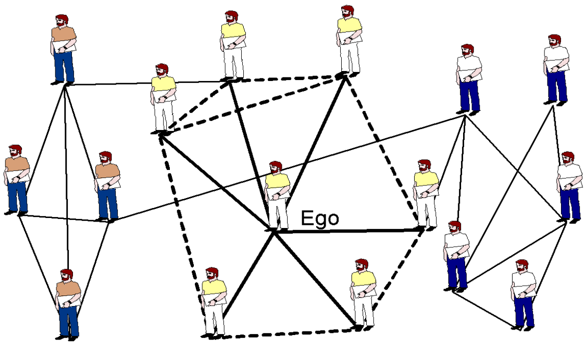

Figure 1. Real, small world, social networks exhibit clustering, the tendency of two individuals who share a mutual friend to be friends themselves

II SMALL WORLD AND AD HOC NETWORKS

Since the people that form a communication network are interconnected in a small world fashion, this interconnection reflects in the source-drain distribution in the ad hoc network they use as a tool for their communication. As a result we can not observe the ad hoc network as a collection of randomly interconnected nodes, nor consider its features using pure random traffic generators. Unlike this unrealistic assumptions, we take into consideration the fact that the communication in the ad hoc network is not random, but small world distributed, which consequently leads to increased ad hoc performances [8][9].

The coupling topology of the social network of the ad hoc users results into a different, small world, approach in the application layer modeling of the ad hoc network communication. That is, the application layer has an

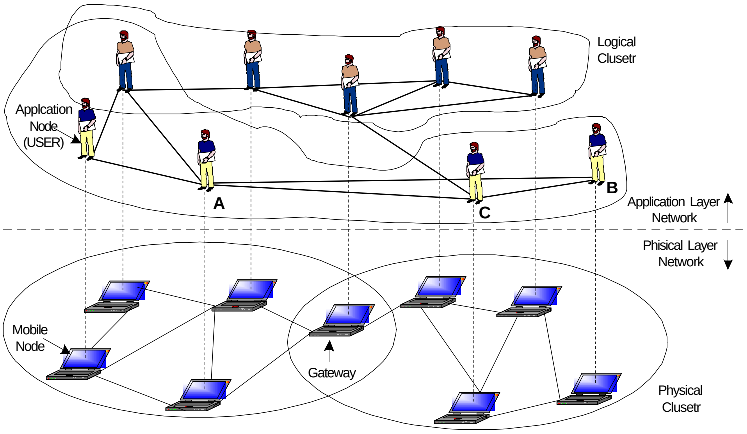

Figure 2. Application Layer and Physical Layer

information about the users friends since the user communicates only with them.

The user social network is expressed on the application layer and is called *logical network* or *application layer network*. The underlining ad hoc network is called *physical network* and may be different from the application layer network (see Fig. 2). Take notice that in most of the cases the users from the same social network also share physical proximity in the ad hoc network. Thus, very often, the physical and logical networks are overlapping.

An important structural property of small world networks is the clustering coefficient [10] that measures the cliquishness of a typical neighborhood and it is a local property. As pointed out by Watts [3] real-world networks show strong clustering or network transitivity. A network is said to show clustering if the, probability of two vertices being connected by an edge is higher when the vertices in question have a common neighbor. That is, there is another vertex in the network to which they both are attached. The clustering effect is measured by a clustering coefficient C, which is the average probability that two neighbors of a given node are also neighbors of one another. In many real-world networks the clustering coefficient is found to have a high value, from a few percent to 50 percent or even more [11].

Another structural property of small world networks is their characteristic path length. The characteristic path length measures the typical separation between two vertices in the graph and is a global property. It is defined as the number of edges in the shortest path between two vertices, averaged over all pairs of vertices. This parameter has not great influence on performance of ad hoc networks [9]. The path length between two nodes in logical network is obviously different from the corresponding path length in physical network, and can be greater or lower depending on the physical proximity of the nodes and positions of the routing nodes. For example, the path length between node *A* and node *B* (see Fig. 2) is 1, but the hop distance in the underlining ad hoc network is 4; the path length between node *B* ad *C* is 1 and the hop distance is also 1. For evaluation of the dependence of performances from the overlapping of logical and physical network, we introduce the average hop distance parameter. The shortest hop distance h_{ij} between nodes i and j is the minimum number of hops needed to send packet from a node i to another node j. By definition $h_{ij} = 1$, and $h_{ij} = 1$ if there is a direct connection between node i and j (node j is in transmission range of node i) in underlining ad hoc network. The average hop distance H of the logical network $G_L(V_L,E_L)$ and physical network $G_P(V_P,E_P)$ is defined as the average of the shortest hop distances between the nodes that are connoted in GL,

$$H(G_L,G_P)=\frac{1}{|E_L|}\sum_{i\neq j\in V_L} h_{ij}$$

$|E_L|$ gives the total number of links in the logical network G_L. Of course, the assumption that G_P is connected is crucial in the calculation of H. It implies that there exists at least one path connecting any couple of vertices with a finite number of steps.

Modelling of physical proximity of nodes is achieved by dividing the area in U sub areas. In each sub area M nodes belonging to a same logical cluster are randomly scattered. This enables creation of clusters on physical layer, and makes the overlapping of logical and physical clusters easy. The logical network is generated with the proposed generation algorithm in [9]. Input parameters for the proposed model are: number of groups (clusters) U, number of nodes per cluster M, average degree of node d, and percentage of in-cluster communications a. The algorithm result is an NxN connection matrix, where N is the total number of nodes (users) and $N=M*U$. The first M nodes belong to first cluster; the nodes with numbers M+1 to 2M belong to second cluster, etc. First, in each cluster $M*d*a$ links between randomly chosen nodes are created. After that $N*d*(1-a)$ links between nodes belonging to different clusters are created. By the mans of the algorithm it is possible to model a wide range social groups i.e. from highly interconnected to strictly independent. We implemented our small world application layer in NS2 in the following fashion. Messages from the application protocol are sent periodically during simulation time. Each period a particular percent of sending nodes is chosen. In the case when the logical network has small world properties each of the sending nodes randomly selects one friend node and sends a message to it. If there isn't logical clustering each of the sending nodes randomly selects any node and sends message to it.

III PERFORMANCE METRICS

For measuring performance of ad hoc networks using the proposed application layer model, the following performance metrics are used: end-to-end throughput, total throughput, clustering performance factor, average hop distance and clustering coefficient. End-to-end throughput is the total amount of bits received by all nodes per second and is measured in bits per second (bps). Total throughput is the total amount of bits transferred through the ad hoc network, and it is calculated by multiplying end-to-end throughput by the average hop distance. In order to quantify the impact of clustering to performance of the ad

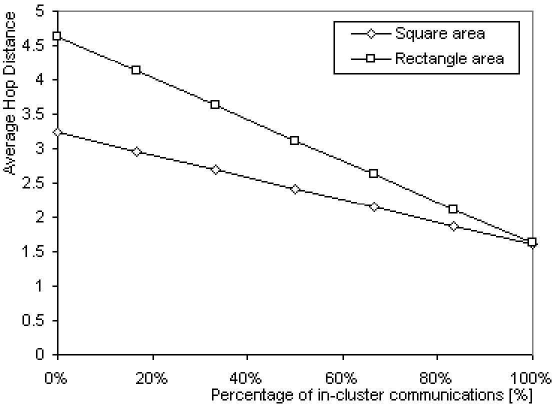

Figure 3. Average hop distance for square and rectancle area depending on the in-cluster communication percentage

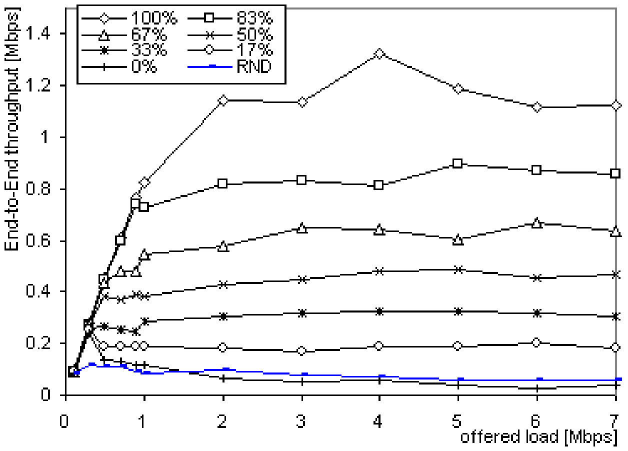

Figure 5. End-to-end throughputs for various in-cluster communications percentage depending on the offered load

hoc network we introduce a new metrics called clustering performance factor (CPF). CPF is defined as a ratio of achieved end-to-end throughput with clustering and end-to-end throughput without it.

IV PRACTICAL USE OF SMALL WORLD APPLICATION LAYER

For the purposes of practical use of small world application layer for analyzing the performances of ad hoc networks, NS-2 [13] network simulator was used. At the physical layer, a radio propagation model supporting propagation delay, omni-directional antennas, and a shared media network interface is used. The IEEE 802.11 Medium Access Protocol is employed at the Link Layer level, and a transmission range is up to 250m, AODV routing protocol [14] in combination with UDP are used.

The values of the parameters for the logical network generation model are: number of clusters U=4, number of nodes per cluster M=25, average degree of node d=12, and percentage of in-cluster communications a is varied from 0% to 100%. The dependence of the clustering coefficient on the in-cluster communications is shown on Fig. 3. In the simulations scenarios two area shapes where nodes are placed are used: square 1*km* x 1*km* and rectangle 0.5*km* x 2*km*. The sub areas are 0.5*km* x 0.5*km* in the both cases. When physical clustering exists in each of the sub areas 25 nodes are randomly placed, and when there is no physical clustering all 100 nodes are randomly scattered in the whole area. The dependence of average hop distance on the in-cluster communications for square and rectangle area is presented on Fig. 4. For smaller in-cluster communications the rectangle area has greater average hop distance as a result of the greater distance between nodes.

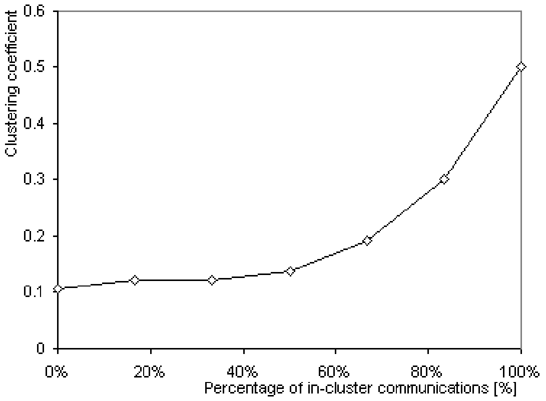

Figure 4. Clustering coefficeint depending on the in-cluster communication percentage

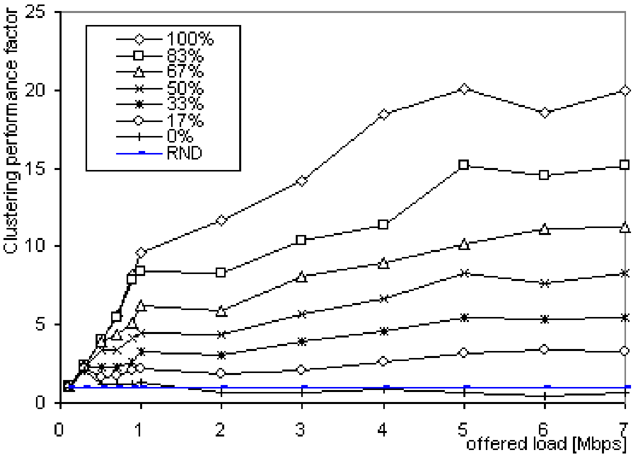

Figure 6. Clustering performance factor for various in-cluster communications percentage depending on the offered load

The clustering coefficient depends directly on the in-cluster communication percentage as shown on Fig 3. Due to usage of in-cluster communications as an input parameter in the proposed algorithm for generation of small world networks we present the dependence of performances of ad hoc network on this parameter. The in-cluster communications are varied from 0% to 100%. For all scenarios nodes are also clustered at physical layer. For result comparison random traffic (without logical clustering) scenario is made. All scenarios are tested with offered load from 0.1Mbps to 7Mbps and square area shape.

Fig. 5 presents the impact of in-cluster communications percentage on end-to-end throughput. The first scenario (100%) where all communications are between the nodes in the same logical and physical cluster, shows highest end-to-end throughput according to the decreased interference between wireless transmissions and possibility of parallel communications in different clusters when the nodes that communicate are on distance greater than the transmission range. In the other scenarios, the end-to-end throughput decreases together with the percentage of communications between nodes in the same cluster. The last scenario (0%)

where all communications are between nodes in different clusters has lowest end-to-end throughput, lesser than the end-to-end throughput of the referent random traffic scenario. The CPF for different percentages of in-cluster communications, Fig 6. The first scenario (100%) shows 20 times (for 6Mbps) better performance than the random traffic scenario. Other scenarios have lower CPFs. It can be seen that CPF grows up when the percentage of in-cluster communications increases.

It can be seen (Fig. 7) that the total throughput has maximum that is reached at the critical average hop distance point. This maximum is capacity of ad hoc network for specified offered load and average hop distance. The capacity of an ad hoc network is lesser for smaller offered loads, as a consequence of larger average hop distance. The larger average hop distance results in more hops and thus in more routing overhead in ad hoc network, which leads to reducing of useful capacity. The capacity of square area ad hoc network is smaller than the capacity of rectangle area ad hoc network, because of smaller possibilities of simultaneous transmission. For large loads, the capacity of ad hoc network is reached with smaller average hop distances and the total throughput is decreasing constantly with the increasing average hop distance. Exception is only 1Mbps offered load in rectangle ad hoc network that reaches capacity at average hop distance equals to 2.7.

VI CONCLUSION

In this paper the small world application layer for ad hoc networks is presented. By analyzing real social networks and real applications of ad hoc networks it can be concluded that application layers show small world properties.

In order to quantify the performances of ad hoc networks that use a small world application layer we introduce several performance metrics: end-to-end throughput, total throughput, clustering performance factor, average hop distance and clustering coefficient. We also illustrate the practical use of the introduced performance metrics.

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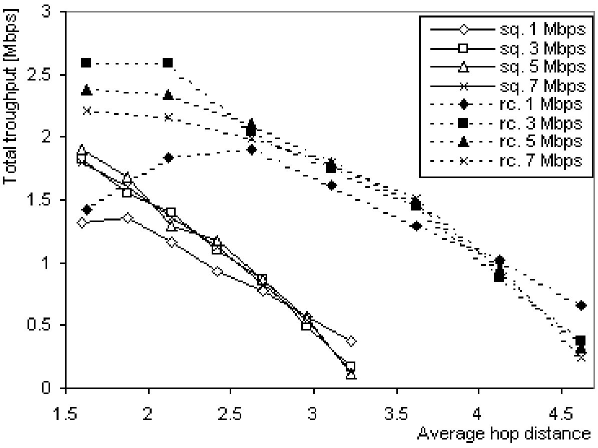

Figure 7. Total throughputs for various large offered load depending on the charachteristic hop distance (sq. – square area, rc.- rectangle area)

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Abstract: The proliferation of mobile devices and the development of ad hoc networks introduces the possibility of an environment where multiple entities will participate in collaborative applications with each other. The main application of wireless mobile ad hoc networks is to offer services for situations wherein groups of people come together and share information. The groups of people that use the ad hoc network form some kind of real social network that exhibits small world properties. In this paper we propose a small world application layer for ad hoc networks. The performances of ad hoc networks are illustrated using several newly introduced performance metrics.

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