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Analysis of small world phenomena and group mobility in ad hoc networks

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***Abstract* – 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 social network. In this paper an analysis of the performances of mobile ad hoc networks is performed when taking into consideration its social characteristics through the small world phenomena of the application layer and usage of group-based mobility. The simulations show that the social interconnection between the network users has an extreme 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.**

I. Introduction

Mobile hosts such as notebook computers are now easily affordable and are becoming quite common in everyday business and personal life. At the same time, network connectivity options for use with mobile hosts have increased dramatically, including support for a growing number of wireless networking products based on radio and infrared. With this type of mobile computing equipment, there is a natural desire and ability to share information between mobile users. In areas in which there is little or no communication infrastructure or the existing infrastructure is expensive or inconvenient to use, wireless mobile users may still be able to communicate through the formation of an ad hoc network. A few examples include: military soldiers in the field; an infrastructure-less network of notebook computers in a conference or campus setting; and temporary offices such as campaign headquarters. An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration.

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 the 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 [1]. From this point of view, most of the communication between the entities is done inside the friends group while the necessity to communicate with a non friend is scarcely rare.

Mobile devices are usually carried by humans, so the movement of such devices is necessarily based on human decisions and socialization behavior. Please note that movement is strongly affected by the needs of humans to socialize in one form or another. Fortunately, humans are known to associate in particular ways that can be mathematically modeled, and that are likely to bias their movement patterns. Thus, it is important to model the behavior of individuals moving in groups and between groups, as is likely in the typical ad hoc networking deployment scenarios. In order to capture this type of behavior, it is necessary to define models for group mobility that are heavily dependent on the structure of the relationships among the people carrying the devices.

In this paper the small world driven communication in combination with an appropriate group mobility model is observed. The main goal is to observe the performances of the ad hoc network when the real social network formed by the network users affects both the application layer and the physical clustering of the socially aware moving nodes, i.e. campus collaboration or military campaign [6].

The remainder of this paper is organized as follows. In Section 2, the interaction between the small world concept and ad hoc network is described. Section 3 describes used simulation methodology, starting with application protocol, then the applied mobility model, scenarios' characteristics and performance metrics. In Section 4 results from simulations of various scenarios are shown. In Section 5 conclusions according to the obtained results are presented.

II. Related Work

In most of the articles on ad hoc network performances traffic in a randomly connected nodes environment is considered. Johansson et al. [2] 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).

When considering ad hoc networks and their employment, the first necessity that arises is to take into account the node's mobility features. However, because of their intrinsic nature ad hoc networks are more than just ordinary networks with mobile nodes. Their utilization is completely dependent on the way the network is utilized by its users. In [10] and [11] the social aspects of the users of the network are imprinted in the mobility model designed for ad hoc networks.

The way the ad hoc network users interact has influence on the network performances in different ways. The user interaction defines the mobility model for the mobile nodes, but also defines the communication pattern between the mobile nodes. Thus, in [3] an application layer with clustering is used in order to investigate the performances of ad hoc networks and in [4] and [5] the effects of small world phenomena clustering on performances of ad hoc networks are observed.

II. Modeling Ad Hoc Network Users

Watts [7] has shown that the connection topology of some biological, technological and social networks is neither completely regular nor completely random but stays somehow in between these two extreme cases. This particular class of networks, named small worlds in analogy with the concept of the small-world phenomenon observed by Milgrim more than 30 years ago in social systems [1], are in fact highly clustered like regular lattices, yet having small characteristic path lengths like random graphs.

A. Small World Communication Pattern

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 [8]. 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. These groups are joined to each other by the overlaps created when individuals in one group also belong to other groups [9]. 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.

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. 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 information about the user’s friends since the user communicates only with them. Thus, the user’s social network is expressed on the application layer and is called logical network or application layer network.

B. Physical Proximity Modeling

The underlining ad hoc network is called physical network and may be different from the application layer network. 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. For an example, when considering a deployment of an ad hoc network for campus students, where each student represents an ad hoc network node, we can view the established ad hoc network logical and physical grouping:

1. logical – the study groups created and interleaved via the students friends that belong to different study groups
2. physical – the movement of each student, which complies to the movement of each study group.

Since most of the communication will be between the participants of the same study group, here we have a classical example of physical and logical groups overlap. The same discussion can be done for a number of different examples of practical ad hoc network establishment.

When reviewing the physical network, it is clear that node mobility is an intrinsic characteristic of ad hoc networks. Thus, the study of ad hoc networks performances in presence of appropriate node mobility represents a fundamental stage of the designer process. In lack of available established ad hoc network, the natural approach is to use a synthetic mobility model in combination with simulations. The mobility model for ad hoc networks should respond to the real life movements of the nodes. That is, in correlation with the many possibilities for ad hoc network deployment, we need a model that will allow representation of the movement of campus students, group of tourists in an urban scenario, rescue groups on the field...

In order to simulate the group mobility behavior of the ad hoc network users, we use the group-based mobility model proposed in [10] that is aware of the social clustering of the network users [11]. In particular, the model allows collections of hosts to be grouped together in a way that is based on social relationships among the individuals. This grouping is only then mapped to a topographical space, with topography biased by the strength of social ties. Individuals move within the sphere of influence of the geographic group with which they are associated at any given point in time.

A host belonging to a group moves inside the corresponding group area towards a goal (i.e, a point randomly chosen in the group space) using the standard Random Way-Point model. It is worth noting that groups also move towards randomly chosen goals in the simulation space. Each group moves with a random speed (with a value contained in a predefined range); moreover, each host moves with a randomly generated different speed (once again, contained in a predefined range). Therefore, the movement of a host that belongs to a group is the result of the composition of these speeds. When two groups meet, each member of one of the groups may leave its group and join the other determined with a given probability.

III. Simulation Methodology and Parameters

For analyzing the performances of mobile ad hoc networks, NS-2 network simulator [12] was used, since it has proven to be one of the most accurate and popular network simulators [13]. 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 [14] in combination with UDP are used.

A. Parameters

The logical small world network is generated with the proposed generation algorithm in [5]. 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 N x N 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 means of the algorithm it is possible to model a wide range of social groups i.e. from highly interconnected to strictly independent.

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 the percentage of in-cluster communications a is varied from 0% to 100%.

The mobility model employed is the group-based mobility model discussed in section II-B. The nodes are moving with speeds varying by a maximum of ± 0.001m/s from the chosen speed of the group, which is held constant at 1, 2, or 5 m/s.

B. Scenario Characteristics

In the simulations, nodes are placed in a square-shaped area of 1km x 1km. The four sub areas, in which the total simulation area is divided, are 0.5km x 0.5km each. When physical clustering exists, the four groups of 25 nodes are placed in a different sub area each, and are allowed to move only within its borders.

When there is no physical clustering, all 100 nodes are randomly scattered in the whole area, and are free to move across the whole simulation area. On the other hand, logical clustering is achieved through our custom made application layer protocol, which makes it possible for the nodes to distinguish between nodes that belong to the same logical cluster (nodes they can communicate with), and nodes from other logical clusters.

When logical clustering is used (i.e. the network manifests small-world characteristics), nodes send messages to their friends only (nodes from the same logical cluster). In the opposite case (the random traffic scenario), destination nodes are randomly chosen from the whole population of nodes, regardless of the logical cluster they belong to.

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

C. Ad Hoc Network Performance Metrics

For ad hoc network performance measuring using the small world application layer in combination with the group mobility model, the following performance metrics are used: end-to-end throughput and clustering 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 clustering to performance of the ad hoc network we use the clustering performance factor (CPF) defined as the ratio of achieved end-to-end throughput with clustering and end-to-end throughput without it (here we have random traffic on application layer and random movement on the physical layer).

IV. Simulation Results

Several sets of simulations were made in order to investigate the behavior of mobile ad hoc networks and the impact of their small-world properties to the network performances.

A. *Logical and physical clustering impact on end-to-end throughput*

In the first set of scenarios, the impact of small-world phenomenon on the performance of mobile ad hoc networks was investigated. Four different scenarios were simulated:

1. Logical clustering with physical clustering (L-1 P-1), i.e. all nodes from a given logical cluster are placed in the same physical cluster;
2. Logical clustering with no physical clustering (L-1 P-0), i.e. nodes from certain logical cluster are randomly placed in the whole area;
3. No logical clustering, but physical clustering only (L-0 P-1), i.e. there are no logical clusters and nodes are placed like in the first scenario;
4. Neither logical, nor physical clustering (L-0 P-0), i.e. no logical clusters and nodes are randomly scattered in the whole simulation area.

In the scenarios with logical clustering, 83% of communications are between nodes of the same cluster and 17% are between nodes of different clusters.

Fig. 1, 2, 3 and 4 present the impact of node mobility for the four different clustering scenarios. The cases when the nodes are static, and are moving with speed of 1, 2 or 5 m/s are shown. Please take into consideration that the vertical axes are not in the same range. It can easily be concluded that the scenario where clustering exists on both logical and physical layer shows the best performances. Even more, while the other scenarios, when clustering exists in one and lacks in the other layer, show great dependence on the node mobility, the scenario for l=1 and p=1 performs very similarly for different node speeds. An interesting remark is the network performance for the case of static nodes. The performances rise for small offered load, and rapidly decrease for higher load as a result of the node immobility. For higher loads there is a significant number of packets throughout the network and it is very difficult to successfully send a packet from one to the other end of the network area. However, when the nodes are moving

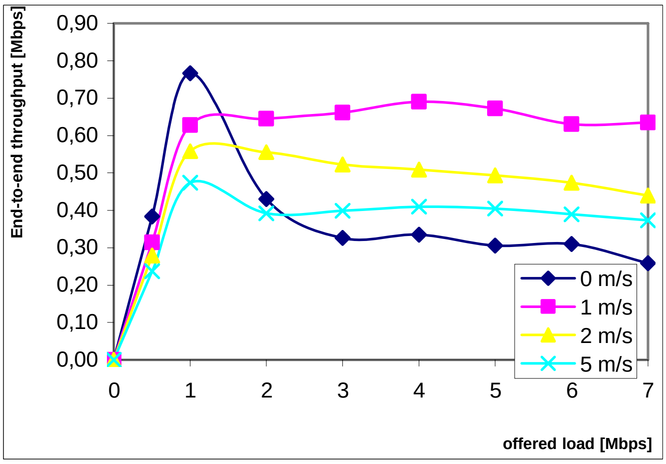

Fig. 1. Impact of the node speed on end-to-end throughput depending on the offered load for L=1 and P=0

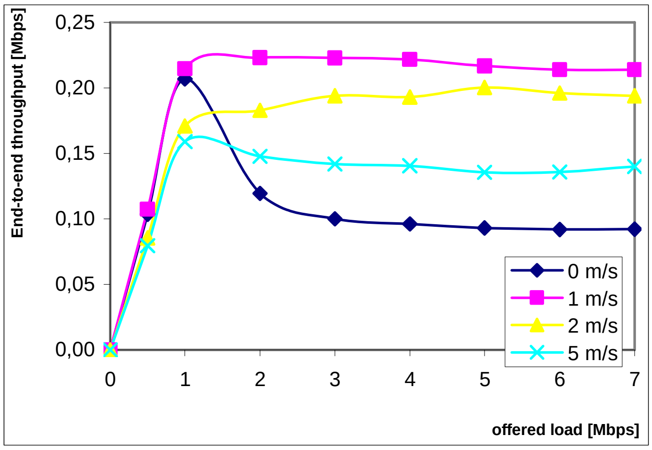

Fig. 2. Impact of the node speed on end-to-end throughput depending on the offered load for L=0 and P=1

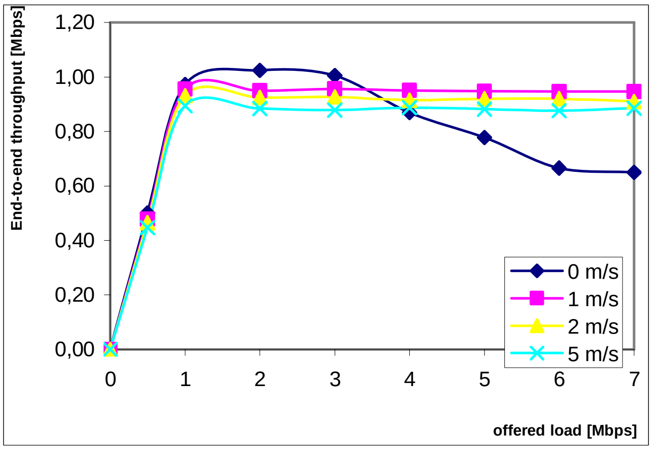

Fig. 3 Impact of the node speed on end-to-end throughput depending on the offered load for L=1 and P=1

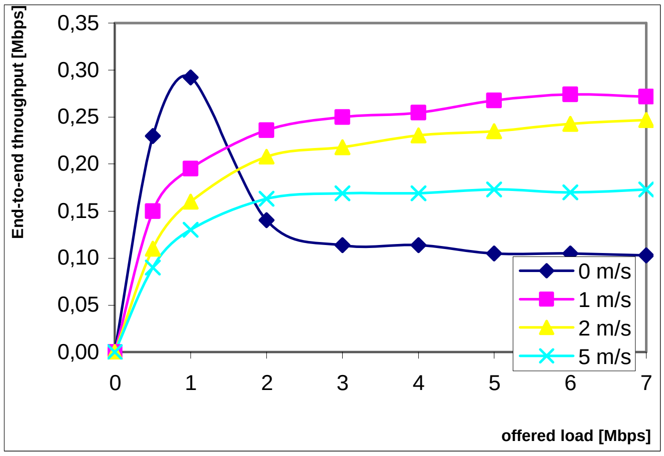

Fig. 4. Impact of the node speed on end-to-end throughput depending on the offered load for L=0 and P=0

relatively slow, the possibility that in some period of time the two nodes that communicate are going to be in range of one another, or are in a small number of hops distance, is very big, thus making the performances of the network rise.

B. Node speed impact in different clustering coefficient

In order to investigate the end-to-end throughput dependency on the in-cluster communications percentage, a second set of scenarios was created. In all scenarios, nodes are logically and physically clustered, with the in-cluster communication percentage varying from 0% to 100%.

Fig. 5 presents the impact of node speed on network performances when all of the communication takes place inside the cluster. Here, the network performance is the greatest for static nodes because of the fixed short source-destination routes.

Again for greater offered load this performance decreases because of the need for a greater number of transmissions in the group area. On Fig. 6 the clustering performance factor is represented for the case of 100% in-cluster communication, and it can easily be concluded that the performances are around 5 times greater when compared to the random scenarios. For the static case, the performances increase up to 15 times.

Fig. 7 represents the impact of node speed on the network performances in the case of 50% in-cluster communication, while on Fig. 8 the clustering performance factor for the same scenario is shown. It is interesting to notice, that while the performances of the network rapidly decrease when considering static nodes, the performances of the network for mobile nodes increase up to 10 times when compared to the random scenarios.

Fig. 9 and Fig. 10 present the impact of node speed on the network performances for 0% of in-cluster communication. In this case, it can be observed that the network performances are very low when the nodes are static, especially when the offered load rises, since now all of the communication is being done with members of other groups and it always includes longer source-destination routes for the packets. Also, in this case the impact of the node speed is more significant.

When taking into consideration all of the phenomena shown on this group of figures it can be concluded that in the case of

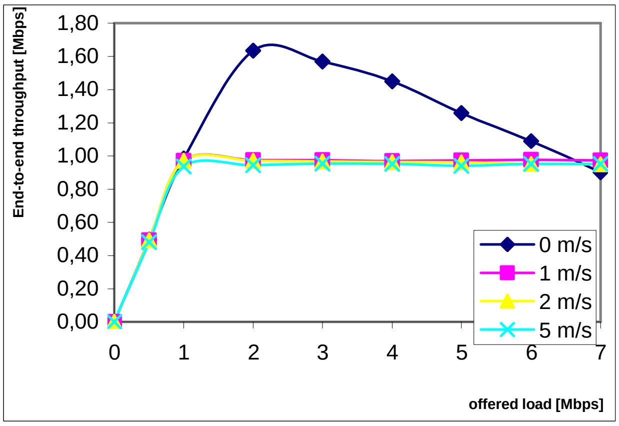

Fig. 5. Impact of node speed on end-to-end throughput depending on the offered load for 100% in-cluster communication

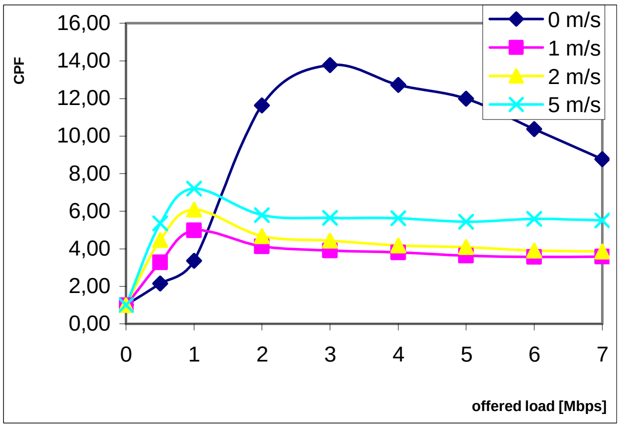

Fig. 6. Clustering performance factor for 100% in-cluster communication and various node speeds depending on the offered load

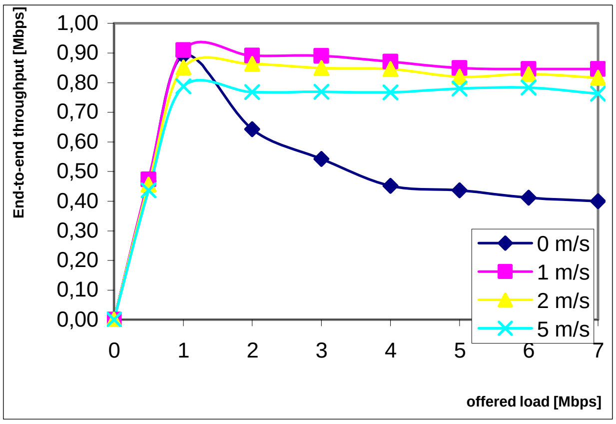

Fig. 7. Impact of node speed on end-to-end throughput depending on the offered load for 50% in-cluster communication

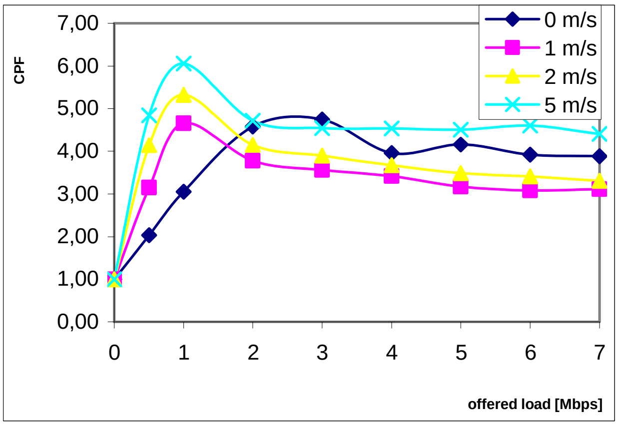

Fig. 8. Clustering performance factor for 50% in-cluster communication and various node speeds depending on the offered load

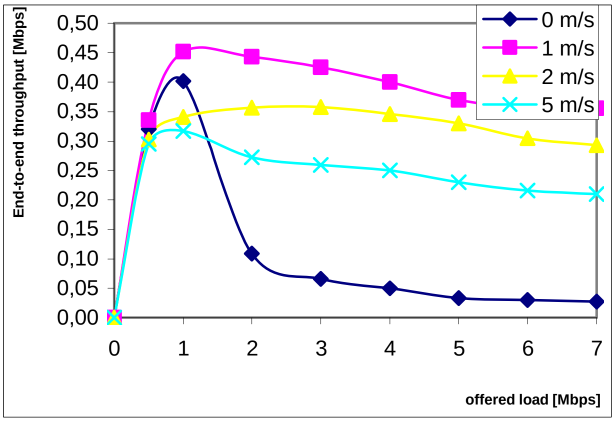

Fig. 9. Impact of node speed on end-to-end throughput depending on the offered load for 0% in-cluster communication

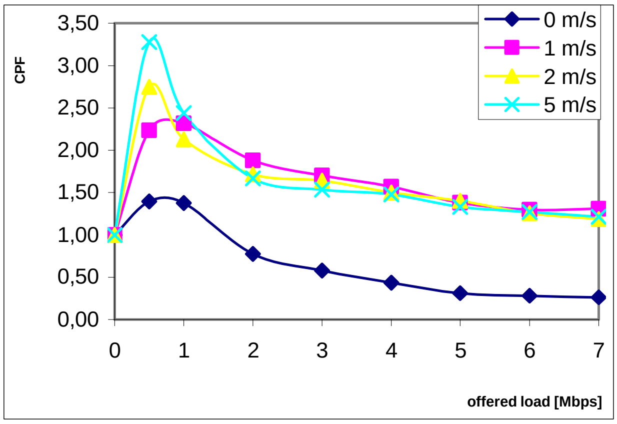

Fig. 10. Clustering performance factor for 0% in-cluster communication and various node speeds depending on the offered load

static network, where the nodes are not moving, performances of the network are rising with the in-cluster coefficient, from the worst performing network for 0% in-cluster communication, where it is better to have mobile than static nodes, to the best performing network for 100% in-cluster communication where the results show that the static network is the one with best performances.

Also, the impact of node mobility is evidently closely connected to the in-cluster communication, from having minimum impact for the case when all of the messages are

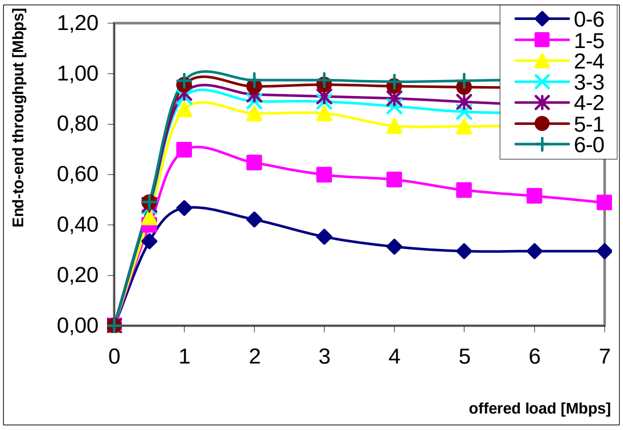

Fig. 11. End-to-end throughputs for various in-cluster communications percentage depending on the offered load

passed between the nodes from the same group, to the last example, when the node speed has significant influence on the network performances when all of the messages are passed between nodes from different groups. The example for 50% of in-cluster communication is, in a way, the break point of the above mentioned tendencies.

C. Impact of different clustering coefficient

Fig. 11 shows the impact of in-cluster communications percentage on end-to-end throughput when considering both physically and logically clustered network with nodes moving with an average speed of 1 m/s. The first scenario (100%), in which all communications are between nodes from the same logical and physical cluster, shows highest end-to-end throughput due to the decreased interference between wireless transmissions and the 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 along with the decreasing of the percentage of communications between nodes in the same cluster. The network performances are especially improved when considering social networks with high in-cluster communication which is to be expected for the social network of the ad hoc network users.

V. CONCLUSION

Analyzing real social networks in combination with the real life possible applications of ad hoc networking it can easily be concluded that clustering appears in both application and physical level. The results in this paper show that when taking in consideration the impact of the underlining social network formed by the ad hoc users on the source-drain distribution of the network packets and on the community based node mobility, the ad hoc networks performances are significantly changed when compared to the randomized scenarios usually employed.

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