Impact of Clustering in Different Layers on Performance of ad hoc Wireless Networks

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Impact of Clustering in Different Layers on Performance of Ad Hoc Wireless 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 real social network. Thus, real social networks exhibit clustering, the tendency of two individuals who share a mutual friend to be friends themselves. In this paper impact of clustering on performance of ad hoc network is investigated. It is shown that clustering has a big influence on the performance. One can conclude that the only way to obtain satisfying performances in large ad hoc network is clustering on physical and logical layer.**

***Index terms* — ad hoc network, clustering, performance, application layer, clustering performance factor.**

1. Introduction

One of the most vibrant and active "new" fields today is that of ad hoc networks [1]. Within the past few years, though, the field has seen a rapid expansion of visibility and work due to the proliferation of inexpensive, widely available wireless devices as well as of the network community's interest in mobile computing.

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. Nodes in an ad hoc network can act as both hosts and routers since they can generate and forward packets. Since there is no existing communication infrastructure (e.g., a wired or a fixed wireless base station), nodes in an ad hoc network are expected to act cooperatively to establish the network "on-the-fly" and route data packets possibly over multiple hops. Node mobility and limited power introduce rapid changes in network topology, connectivity and links characteristics. 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; sensors scattered throughout a city for biological detection; an infrastructure-less network of notebook computers in a conference or campus setting; the forestry or lumber industry; and temporary offices such as campaign headquarters

The main application of wireless mobile ad hoc networks is to offer services for situations wherein groups of people come together for a short time and share information [2]. The groups of people that use the ad hoc network form some kind of real social network. Thus, real social networks exhibit clustering, this is the tendency of two individuals who share a mutual friend to be friends themselves [3]. This observation turns out to be an almost universal feature, not just of social networks, but networks in general. The social networks are much more like one presented in Figure 1. The 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, joined to each other by the overlaps created when individuals in one group also belong to other groups.

Existence of clustering in network of people who use ad hoc network to communicate and share information, implicates clustering in the application layer of an ad hoc network. Hence, in this paper, the impact of clustering in different network layers, like application and physical, to the overall performance of the ad hoc network is examined.

The remainder of this article is organized as follows. In Section 2, related work is presented. In Section 3, aspects of clustering in ad hoc networks are shown. Section 4 describes used simulation methodology, starting with application protocol with clustering, then used routing protocols, scenarios characteristics and clustering performance metrics. In Section 5 results from simulations of various scenarios are shown. In Section 6 conclusions according to the obtained results are presented.

2. Related Work

Several recent studies have addressed mainly the technical side of performances of ad hoc networks. In [5] the interaction between TCP and MAC layers in a wireless multi-hop network is investigated. In [6], [7] and [8] the performances of TCP over different routing protocols in ad hoc networks are analyzed using NS-2 simulator [13]. Brosh et al. [9] presents the results of a detailed packet-level simulation comparing four multi-hop wireless ad hoc network routing protocols that cover a range of design choices: DSDV (Destination Sequenced Distance Vector), TORA (Temporally-Ordered Routing Algorithm), DSR (Dynamic Source Routing), and AODV (Ad-hoc On Demand Distance vector). They have extended the *ns*-2 network simulator to accurately model the MAC and physical-layer behavior of the IEEE 802.11 wireless LAN standard, including a realistic wireless transmission channel model. In [10] the factors that affect the capacity of ad hoc networks, like network size, traffic patterns, and detailed local radio interactions, are examined using simulation and mathematical analysis. Johansson et al. [11] made a comparison of three routing protocols (DSDV, AODV and DSR) proposed for wireless mobile ad-hoc networks. They simulate three realistic scenarios to test the protocols in more specialized contexts. The scenarios include rescue operations in remote areas, or when local coverage at a remote construction site must be quickly deployed; ad-hoc networks between notebook or palmtop 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 and a PDA) for elimination of need for cables.

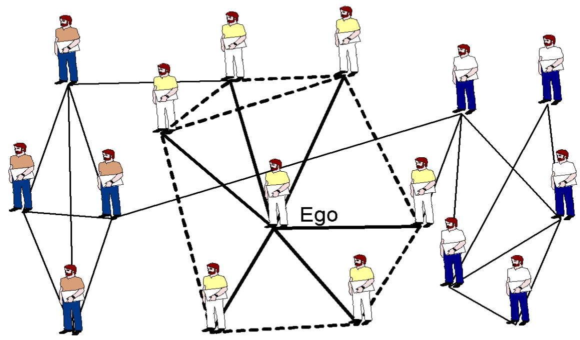

Figure 1 Real social networks exhibit clustering. Here, Ego has six friends, each of whom is friend with at lest one other

3. Clustering in Ad Hoc Networks

The basic concept of the clustering idea is to group some “neighboring” nodes together into a cluster, i.e. a cluster is subsets of nodes that can (two-way) communicate with each other. 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 [4].

In this paper we define two types of clustering in an ad hoc network: *logical* (application) and *physical* (topological). While logical clusters represent people friends in an application view, physical clusters are based on the topological connectivity of the mobile devices (see Figure 2). To enable communications between nodes belonging to different clusters there must be nodes that belong to more than two clusters at the same time (called gateways).

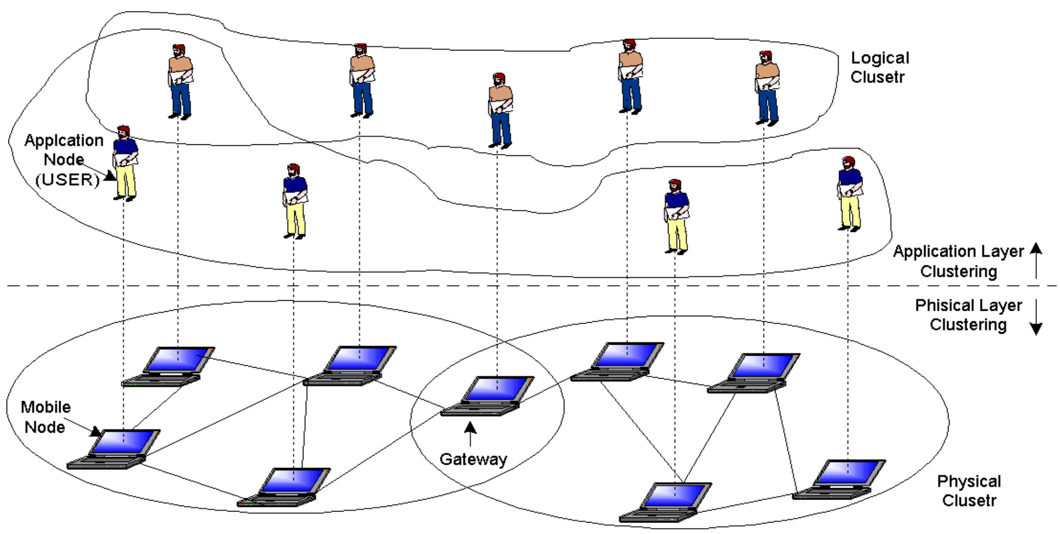

Figure 2 Application Layer and Physical Layer clustering

4. SIMULATION METHODOLOGY

For the purposes of simulating and analyzing the behavior of clustering in ad hoc networks, NS-2 [13] network simulator from Lawrence Berkley National Laboratory (LBNL) was used as one of the most accurate and popular ones [12].

Application Protocol with Clustering

NS-2 does not include an application layer protocol that is aware of any logical cluster division of a population of nodes. Hence we created custom type of application layer protocol that has this feature. That is, only logically connected nodes are allowed to communicate one another. By creating a custom type of application level, we take a certain logical view over the population of nodes whose behavior we want to observe. Therefore, we can influence the creation of logically based clusters, leaving their physical organization intact. By the means of its application layer, each node in a given population, knows which its friends are, or, more exactly, which are the nodes it can communicate with. For creation of connectivity matrix two parameters are used: the mean value of the number of connections in each logical cluster per node and the mean value of the number of connections outside of the logical cluster per node. By the means of these two parameters it is possible to model a range of all social groups i.e. from highly interconnected to strictly independent.

Since TCP is adding a lot of complexity and thus masking clustering effects, the created application protocol uses UDP communication only.

Routing Protocols

The most vital part of an ad hoc network is the routing protocol. The primary goal of the routing protocol is correct and efficient route establishment between pair of nodes so that messages can be delivered in a timely manner. The NS-2 supports four ad hoc routing protocols: DSDV, DSR, AODV and TORA. In the simulations two different routing protocols are used to compare impact of clustering on their performance. We chose DSR and AODV because they have better performance then DSDV and TORA [9][11]. AODV [14] as a reactive distance vector routing protocol, requests a route only when needed and does not require nodes to maintain routes to destinations that are not communicating. The process of finding routes is referred to as the route acquisition henceforth. AODV uses sequence numbers to avoid routing loops and to indicate the freshness of a route. DSR [15] is a reactive routing protocol that uses source routing to deliver data packets. Headers of data packets carry the sequence of nodes through which the packet must pass. This means that intermediate nodes only need to keep track of their immediate neighbors in order to forward data packets. The source, on the other hand, needs to know the complete hop sequence to the destination.

Scenario Characteristics

For the performance analysis of clustering effects we considered a wireless ad-hoc network of 100 mobile nodes, placed on an area of 1000m x 1000 m, with each node having a transmission range up to 250m. All nodes communicate with identical wireless radios. At the physical layer, a radio propagation model supporting propagation delay, omni-directional antennas, and a shared media network interface is used. The IEEE 802.11b Medium Access Protocol is employed at the Link Layer level.

The logical clustering is realized with our new application protocol with clustering. When logical clustering is used, a node can communicate only with its friends. The nodes are clustered in four equal clusters, i.e. 25 nodes per cluster. If there is no logical clustering, every node can communicate with all other nodes. The physical clustering is achieved through node-positioning scenario where 100 nodes are placed on 1000m x 1000m square area. When we use physical clustering, the 1000m x 1000m square area is divided into four 500m x 500m squares. In each of the squares 25 nodes are placed randomly. When there is no physical clustering all 100 nodes are randomly scattered in 1000m x 1000m square area.

Clustering Performance Metrics

In this paper two performance metric are used: *end-to-end throughput* and *clustering performance factor*. End-to-end throughput is 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 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.

5. SIMULATION RESULTS

In order to investigate impact of clustering on performance of ad hoc network we have created and tested several simulations scenarios. Messages from application protocol are sent periodically during simulation time. Each period a particular percent of sending nodes is chosen. In the case of logical clustering 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. For example total offered load is 1Mbps, packet size is 1000 Bytes and 25% of nodes send messages, means that: 25 randomly chosen nodes send messages to their friends 5 times per second. At these conditions, each node generates mean traffic of 10Kbps. Each simulation scenario is defined by specifying the following parameters: logical and physical clustering, number of friends in the cluster, number of friends out of the cluster, offered load, packet size, percent of nodes that send messages and routing protocol.

AODV and Clustering

In the first set of scenarios AODV routing protocol is used, while the offered load is varied from 1Mbps to 7Mbps (10Kbps to 70Kbps per node). Three scenarios are simulated:

1. Logical clustering with physical clustering (L-1 P-1), i.e. all nodes from logical cluster are placed in the same physical cluster;
2. Logical clustering with no physical clustering (L-1 P-0), i.e. nodes from one logical cluster are randomly placed on whole 1000m x 1000m area.
3. No logical clustering but physical clustering only (L-0 P-1), i.e. there are no logical clusters and the nodes are placed like in the first scenario.

Since different placement of nodes leads to different performance in an ad hoc network, in the third scenario we use the same node placement as in the first scenario in order to compare impact of clustering on the same ad hoc network topology. We did not present results for scenario without any clustering (L-0 P-0) because simulation results are almost equal to the results form the third scenario as one could expect. In case of logical clustering 83% of communications are within the nodes of the same cluster and 17% are within the nodes of different clusters.

Figure 3 presents the impact of clustering to end-to-end throughput in the case when AODV routing protocol is used, for offered load from 1Mbps to 7Mbps. The first scenario (L-1 P-1) where logical and physical clustering exist shows much better performance than the third scenario (L-0 P-1). The second scenario (L-1 P-0) shows better performance than the third scenario because nodes communicate only with their friends, and after routes to all friends are discovered there is no additional routing layer overload. The third scenario has the lowest end-to-end throughput as a result of the random pattern for communications. The CPF when AODV routing protocol is used for offered load from 1Mbps to 7Mbps is shown on Figure 5. This metric shows interesting results. The first scenario (L-1 P-1) shows from 8.3 times (for 1Mbps) to 15.2 times (for 7Mbps) better performance than the third scenario (L-0 P-1), CPF grows up when offered load increases as a consequence of more faster congestion of unclustered ad hoc network. The second scenario (L-1 P-0) also shows better performance than the third scenario.

DSR and Clustering

In the second set of scenarios DSR routing protocol is used, and the offered load is varied from 1Mbps to 7Mbps (10Kbps to 70Kbps per node). The scenarios are the same as previous, when AODV was used.

Figure 4 presents the impact of clustering to end-to-end throughput in the case when DSR routing protocol is used, for offered load from 1Mbps to 7Mbps. Like in the AODV case, the first scenario (L-1 P-1) shows much better performance than the third scenario (L-0 P-1), but as the offered load increases the end-to-end throughput decreases as a result of the worse performance of DSR at high loads (like in [11]). The second scenario (L-1 P-0) shows better performance than the third scenario but the escalation is not as great as in AODV case. When DSR routing protocol is used, the CPF for offered load from 1Mbps to 7Mbps is shown on Figure 6. In the first scenario (L-1 P-1) CPF is from 27 (for 1Mbps) to 12.5 (for 7Mbps) and it gets smaller when the offered load increases as a result of the poor performance of DSR at high loads. The second scenario (L-1 P-0) shows better performance in average 2 times than the third scenario. When the offered load is lower, and clustering exists at logical and physical layer, the performance of the ad hoc network using DSR increases much more (27 times) than the performance of the same ad hoc network using AODV (8.3 times). But at higher loads, AODV performs better. The end-to-end throughput in AODVs case is higher than in DSRs case for all offered loads except for 1Mbps where DSR has higher end-to-end throughput.

Impact of in-cluster communications percentage on ad hoc network performance

In order to investigate the performance dependency of the communications percentage that is within nodes in the same cluster, third set of scenarios was created. In this set of seven scenarios we use both logical and physical clustering. In the first scenario 100% of the messages are sent to nodes in the same cluster, in the second scenario 83% of the messages are sent to nodes in the same cluster, and the rest of 17% to nodes in different clusters. In the third, forth, fifth and sixth scenario 66%, 50%, 33% and 17% messages are sent in the same cluster respectively. In the last scenario 100% of the messages are sent to nodes in different clusters. For comparison of results random traffic (without logical clustering) scenario is made. All scenarios are tested with offered load from 1Mbps to 7Mbps and the AODV routing protocol is used.

Figure 7 presents the impact of in-cluster

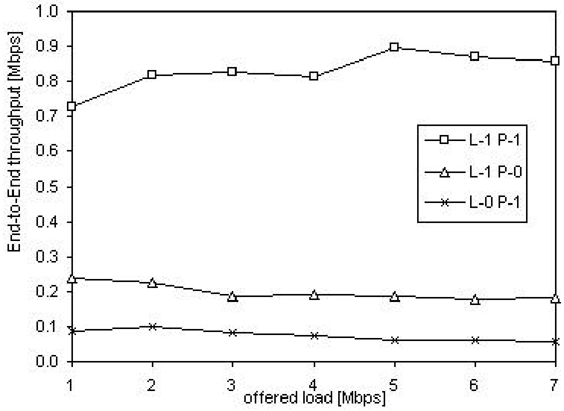

Figure 3 Impact of clustering to end-to-end throughput when AODV is used

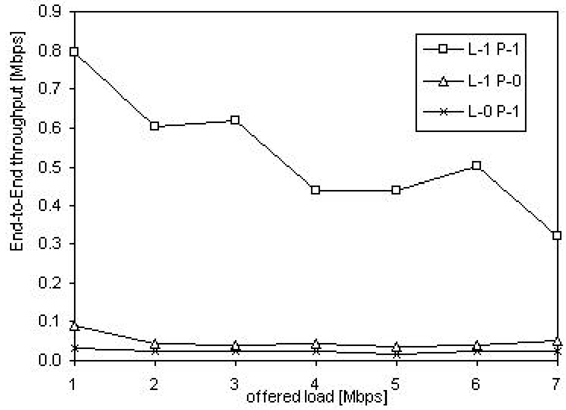

Figure 4 Impact of clustering to end-to-end throughput when DSR is used

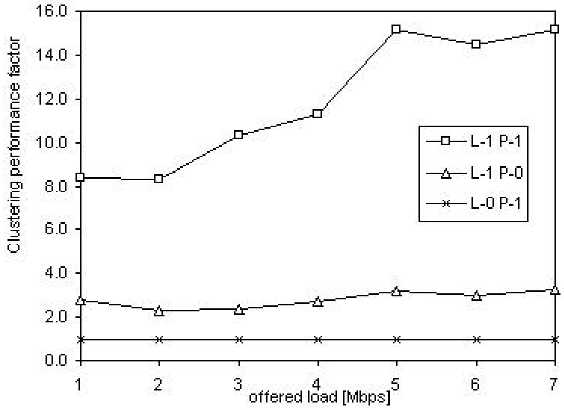

Figure 5 Clustering performance factor when AODV is used

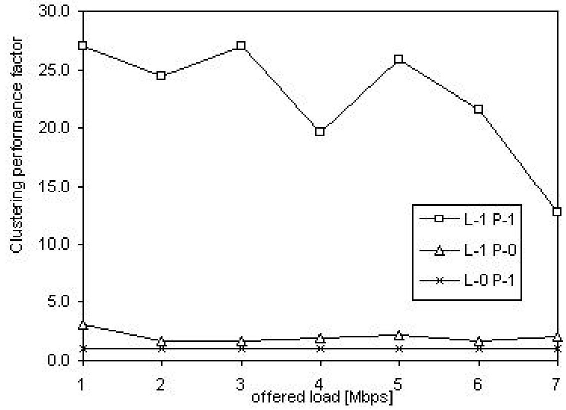

Figure 6 Clustering performance factor when DSR is used

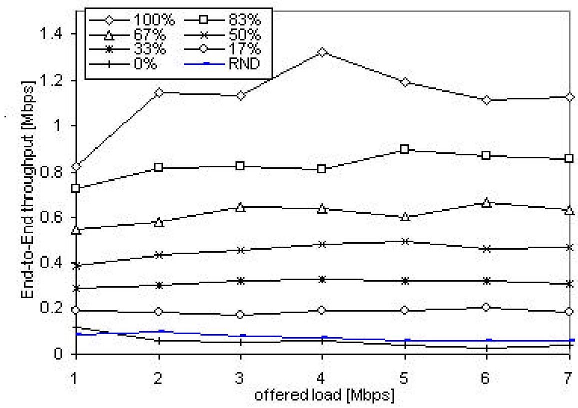

Figure 7 end-to-end throughputs for various in-cluster communications percentage

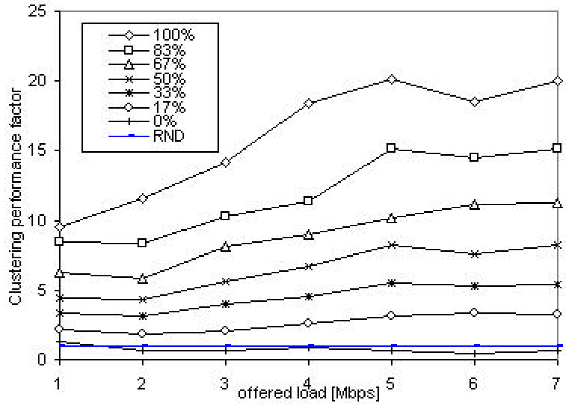

Figure 8 Clustering performance factor for various in-cluster communications percentage

communications percentage on end-to-end throughput, for offered load from 1Mbps to 7Mbps. 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 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 the lowest end-to-end throughput, lesser than the end-to-end throughput of the referent random traffic scenario.

This small end-to-end throughput is a consequence of the fact that all communications are within nodes that are on average greater distance than that in the random traffic scenario.

The CPF for different percentages of in cluster communications, for offered load from 1Mbps to 7Mbps is shown on Figure 8. The first scenario shows from 9 times (for 1Mbps) to 20 times (for 7Mbps) better performance than the random traffic scenario. Other scenarios have lower CPFs. It can be seen that CPF grows up when percentage of in cluster communications increases.

Figure 9 presents the CPF dependency of various offered loads for in-cluster communications percentage from 0% to 100%. It can be seen, that by increasing the percentage of in-cluster communications the performance of ad hoc network also increases. In addition, when the offered load grows up the CPF also increases.

6. CONCLUSION

In this paper, the impact of clustering on the performance of ad hoc networks is investigated. Analyzing real social networks and real applications of ad hoc networks it can be concluded that application layer and physical layer show clustering effects. For testing the impact of clustering to performance of an ad hoc network, a new application layer protocol with clustering was developed for NS-2. In order to quantify the impact of clustering to the performance of the ad hoc network new metrics called clustering performance factor (CPF) is introduced. CPF is defined as ratio of achieved end-to-end throughput with clustering and end-to-end throughput without it. When the offered load is lower, and clustering at logical and physical layer exists, performance of the ad hoc network using DSR increase much more (27 times) than performance of the same ad hoc network using AODV (8.3 times). But at higher loads, the AODV performs better. The CPF when AODV is used, for offered load from 1Mbps to 7Mbps, has average value of 11.9, while when DSR is used the average value is 22.6. When there is logical clustering only, the average values for CFP are 2.7 and 2 for AODV and DSR respectively. By increasing the percentage of in-cluster communications the performance of ad hoc network also increases. In addition, when the offered load grows up the CPF also increases. The key result of the performed analysis is the conclusion that logically and physically clustered ad hoc networks have much better performance than unclusterd ones.

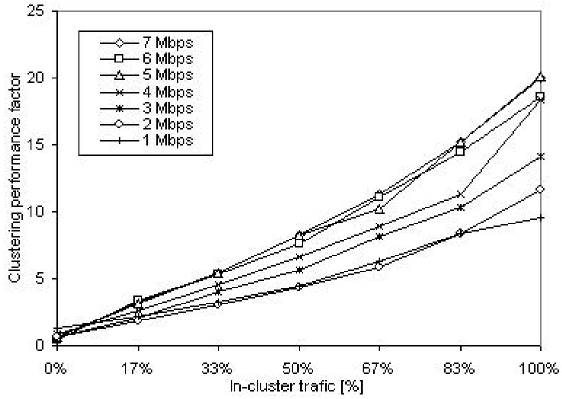

Figure 9 Clustering performance factor for various offered loads

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