Enhancing the Performance of Mobile Ad Hoc Networks with the Aid of Internet Gateways[1]

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Abstract - *Mobile ad hoc networks allow mobile nodes to communicate with one another without the aid of infrastructure thus forming temporary networks on the fly. While such networks are gaining immense popularity, they are prone to scalability issues when the network size (number of nodes) increases, causing the path length between the source and destination to increase linearly. Hence a large number of intermediate nodes are burdened with the forwarding load imposed by other mobile nodes, drastically affecting the performance of ad hoc networks. In this paper, a technique to enhance the performance of MANETs is implemented based on existing infrastructure, which is originally to provide Internet access to MANET nodes resulting in infrastructured MANET. The base stations not only play as gateways to Internet but also serve as intermediate nodes between MANET nodes, thus taking responsibility of relaying most of the burden (packets) imposed by the mobile nodes in the network. Our simulation focuses on assessing performance gains with the introduction of the proposed gateways.*

I. INTRODUCTION

Wireless networks consisting of mobile devices coupled with wireless connectivity are becoming an essential part of the future computing environment. Such wireless networks can be broadly classified into two categories according to their dependence on communication infrastructure - infrastructured and infrastructureless networks. Networks in the first category are designed based on the cellular architecture in which nodes communicate via fixed centralized base stations. These base stations control all the transmissions in the network and forward the data to the intended destinations. Examples of such networks are the cellular phone network and the *Wi-Fi* networks that provide Internet connectivity to mobile users.

A network in the second category consists of mobile devices that use other mobile nodes as routers to route their packets to their intended destination. Such a network is called *Mobile Ad hoc Network (MANET)*. These networks form a temporary communication network in battlefields and disaster struck areas where the wired infrastructure is unavailable or disrupted. While the deployment and configuration of MANETs can be effortlessly done, a major obstacle is that the location based routing cannot be used due to node mobility because not only the source and destination but also the intermediate nodes (acting as routers) are mobile. An intelligent routing protocol must be employed so that each node dynamically finds and maintains routes to destinations. In addition to the efficient routing, the scalability of MANETs is another issue on which there has been a lot of research. When the size of a MANET increases the average distance between the source and destination increases linearly, which results in larger delay and drastic decrease in per node capacity. This is mainly due to the large amount of forwarding load imposed on the intermediate nodes. Random access-based *MAC (Medium Access Control)* protocols, as used in *IEEE 802.11* standard, aggravates the situation by increasing the amount of competition a node faces for transmissions as discussed in [5]. Their results show that the end-to-end throughput available to each node degrades as $O(1/\sqrt{n})$, where n is the number of mobile nodes. Another related study showed that the average throughput available to each node is shown to degrade as $O(1/\sqrt{(nlogn)})$ and that $O(1/\sqrt{n})$ is only achievable when the nodes are optimally placed and the range of each transmission is optimally selected [3].

According to the aforementioned discussion, the effective bandwidth of a MANET decreases as the number of nodes within the MANET increases. In a large scale MANET, data packets must go through a large number of intermediate nodes before reaching the destination limiting the scalability. In addition to data packets, the overhead induced into the network due to the flooding of control packets in the entire network limits the scalability drastically. Two simple solutions are discussed below, one for reducing the number of intermediate nodes and the other one for reducing the control overhead.

In [2], the authors exploit the node mobility to improve the average long-term throughput per source-destination pair. They propose that a source node should broadcast its packet to its one-hop neighbors and let one of them deliver the packet to the destination. Since nodes are

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moving all the time, there is a high probability that at least one relay node gets closer to the destination. This approach does not require any fixed infrastructure and hence it is cost effective. However the delay incurred due to this approach can be tremendous and hence the solution is limited to high delay tolerant applications.

Control overhead is incurred in order to find and maintain the routing paths among nodes. A clustering scheme has been proposed to reduce the control overhead in a large scale MANET [9]. It dynamically builds a hierarchical ad hoc network with backbone nodes, which take care of relaying control packets (possible data packets too) on behalf of other nodes. This scheme breaks a large MANET into a number of small clusters, each with a backbone node and the flooding of the control packets are limited to the backbone nodes. The main advantage of this scheme lies in the selection and maintenance of the backbone nodes as well as overloading on those backbone nodes.

However, both the aforementioned techniques require radical modifications to the underlying MANET routing protocol. This paper suggests improving the MANET scalability by utilizing the Internet gateway with minimal modifications to the MANET routing protocol. Such gateways were originally introduced to provide Internet access to MANETs as proposed in [1, 10, 11, 12, 13, 14], but can be used to facilitate communication between MANET nodes. In [6] the authors have analytically shown that the capacity of a MANET can be improved significantly by the introduction of $\sqrt{n}$ gateways where n is the number of nodes in the network. Our aim is to design and evaluate the infrastructured MANET and compare it with the analytical result. A unique feature of the design proposed in this paper is that the nodes in the MANET are not required to know about the presence of such gateways and hence we call them *Transparent Ad hoc Network Gateways or* TANGs, which act as relay nodes and collectively form a backbone network similar to that discussed in [9]. *Ad Hoc On-Demand Distance Vector* (AODV) [7] routing protocol is used in this study and the proposed scheme was simulated in the *Qualnet* simulator [8].

The rest of the paper is organized as follows: The following section presents our solution to improve the performance of MANETs based on TANGs. Section III describes the simulation environment and presents the simulation results. Section IV concludes this paper.

II. TRANSPARENT AD HOC NETWORK GATEWAY

A. Basic Concept

As discussed in Introduction, a MANET has an inherent scalability problem. Recently, some researchers analytically showed that it could be improved drastically by introducing infrastructured nodes into the MANET [6]. In this section, TANGs are proposed for that purpose. A large scale MANET is divided into equal sized cells and each cell includes a TANG as seen in Figure. 1. However such a division of the MANET into cells is completely transparent to the MANET nodes as they are not aware of the presence of these gateways in the MANET. The primary goal of TANG is to enhance the performance of the MANET and we assume that TANGs are static nodes with wired connectivity and that they can behave as relay nodes in the transmission of packets (data and control) and not as sinks or sources.

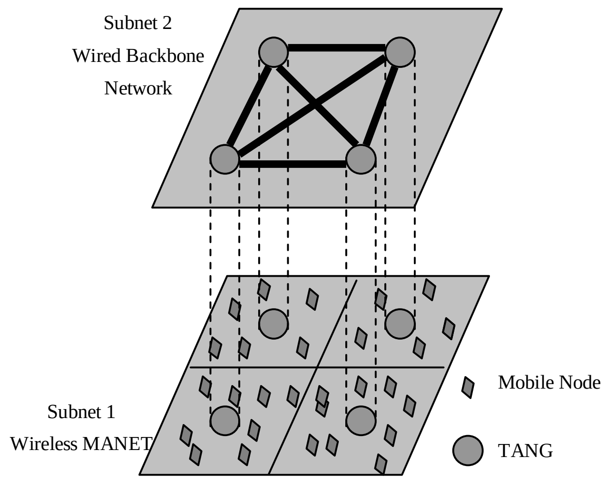


Figure 1: TANGs in a MANET.

Implementation of TANG in a MANET does not require any modification to the underlying MANET routing protocol as mentioned earlier. The introduction of TANG into a MANET, divides the MANET into two different subnets as seen in Figure 1. A pure MANET resides on subnet 1 and the MANET nodes communicate with one another via their wireless interface. On subnet 2 the TANGs form a wired network thus forming a backbone network, as indicated by the solid lines in Figure 1. The communication between the MANET nodes can take place via TANG or via the normal multi-hop links. However, it should be noted that TANGs operate the MANET routing protocol on both subnets as opposed to the Internet gateways, which uses the MANET routing protocol on one subnet and the IP protocol on the other subnet [1]. Due to this there is no complexity concerning TANG and they can be considered normal MANET nodes with the exception of having two interfaces. As mentioned earlier the routing protocol used in this implementation is AODV. This implementation of AODV follows the specification of AODV Internet Draft 9 [7]. As per this draft AODV should be able to handle multiple interfaces.

B. Operation of TANG

Whenever the TANG receives an RREQ it first checks to see if it has a route for the originator of the RREQ. If not, it generates an entry in its route table, which has all the necessary information. Along with this information it also makes a note (in its route table) of the interface on which the RREQ was received. Thus when a TANG receives an RREP for the originator of the RREQ, it will be aware of the interface on which the message is to be forwarded. Whenever the TANG receives a broadcast message like an RREQ from the originator, the TANG is supposed to re-broadcast the message on all its interfaces except the interface on which it has received the RREQ.

C. Advantages of TANG

The time required to do the network-wide search for a destination reduces drastically as the RREQs are forwarded over the backbone link. This leads to a prompt response from the destination reducing the end-to-end delay drastically. Moreover due to the reduced path length between the source-destination the per-node throughput and the overall capacity of the MANETs increase tremendously.

III. Simulation Model

This section introduces the simulation setup to evaluate the performance of the proposed infrastructured MANET and presents the simulation results. The simulation are conducted to address the following issues:

- Performance of infrastructured MANET as compared to a pure MANET.
- Relationship between the number of gateways in the network and the performance of the network.
- Scalability of an infrastructured MANET.

To study these issues the simulation study is divided into two parts. The first part aims at studying the first two of the aforementioned issues by simulating 100 mobile nodes randomly distributed over a rectangular area of 2200m x 600m with varying mobility and number of gateways. To study the scalability of infrastructured MANETs the second set of experiments were conducted by simulating 100, 200 and 500 nodes in an area of 2200m x 600m, 3200m x 900m and 5000m x 1000m respectively.

A. Movement and Communication Model

The mobility model used in this study is the *Random Waypoint Model* [4]. The communication model is determined by four factors: number of sources, packet size, packet rate and the communication type. This study uses the *CBR (Constant Bit Rate)* communication type, which uses *UDP (User Datagram Protocol)* as its transport protocol. In the first set of experiments 40 CBR sources are used to generate network traffic with a packet rate 4 packets/sec. In the second set of experiments 20 CBR sources are chosen with a packet rate of 4 packets/sec. The packet size of 512 bytes was used throughout the simulation.

B. Performance Metrics

The performance metrics used to evaluate the performance of an infrastructured MANET and a pure MANET are (i) throughput, (ii) end-to-end delay and (iii) packet delivery ratio. In order to understand the main causes of performance degradation, the routing-related control overhead associated with the AODV routing protocol is measured. Thus, the number of duplicate RREQ packets generated and the number of RERR packets initiated were used in the performance evaluation.

C. Varying Mobility and Fixed Number of Nodes

These set of simulations are conducted for 100 mobile nodes with varying number of TANGs (2,6,8 and 10 TANGs). As seen in Figure 2, the throughput achieved from infrastructured MANETs (~0.65 Mbps) with 8 and 10 TANGs are almost 6.5 times greater than that achieved by a pure MANET (~0.09 Mbps). Even with 2 TANGs the throughput (0.2–0.32 Mbps) achieved is twice as much as that obtained by a pure MANET. The main reason for such low throughput in a pure MANET is, for a highly loaded network there are many transmissions and hence the nodes are burdened with forwarding the data and routing information of other mobile nodes thus decreasing the throughput drastically. But in case of infrastructured MANETs due to the backbone infrastructure the intermediate nodes are relieved of this burden and hence enhancing the throughput tremendously.

As seen in the Figure 3, the delay for a infrastructured MANET with 8 and 10 TANGs is almost 20 times less than that achieved by a pure MANET and a infrastructured MANET with 2 TANGs (except at low pause times). The reason for such improved performance is due to the fact that the path length between the source and destination reduces drastically with the presence of the backbone infrastructure. Infrastructured MANETs with 8 and 10 TANGs (Figure 4) delivers almost 98% of the packets for lower pause times and almost 100% for higher pause times thus performing more than 5 times better than pure MANETs. The delivery ratio is less than 20 percent for a pure MANET indicating how a MANET fails completely. However as seen in the Figure 4 infrastructured MANETs with 2 TANGs still perform twice as much as compared to pure MANETs.

This part of the section shows the corresponding traffic overhead per data packet originally transmitted from source nodes. It is noted that the number of data packets generated during the simulation is 32,000, which is obtained based on the calculation: 40 sources x 4 packets/sec x 400 simulation seconds/2. The last divisor (2) is introduced because those 40 sources start their data transmission at any random instance between 0 and 400 seconds. If there are 5 intermediate forwarding nodes on the average, total data packets transmitted amount to 160,000.

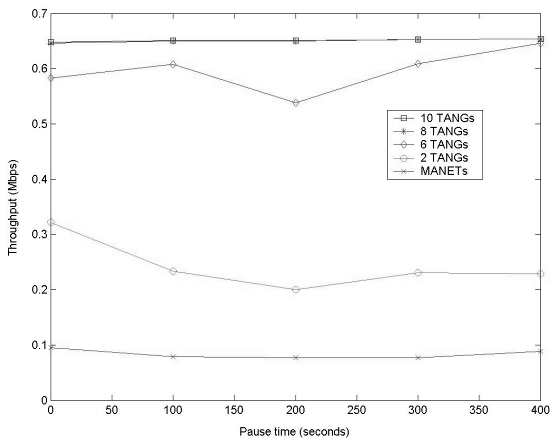


Figure 2: Throughput graph.

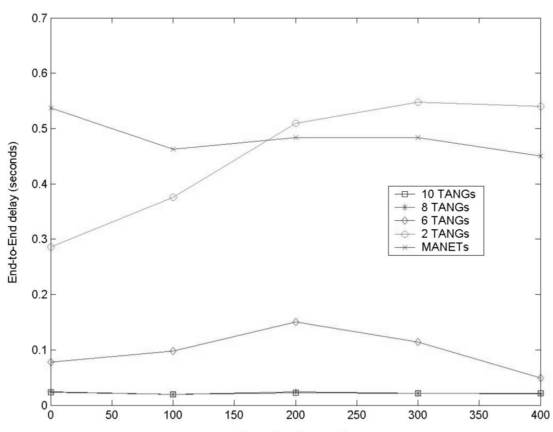
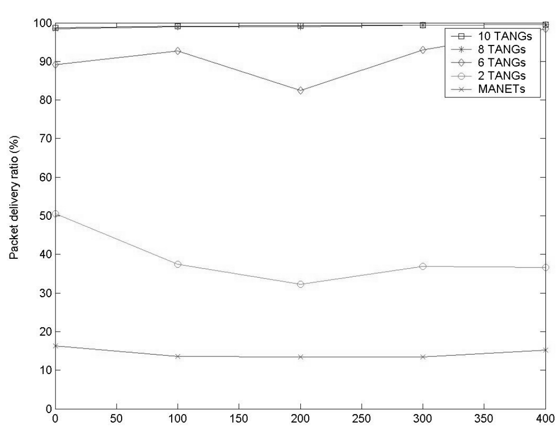


Figure 3: End-to-end delay graph.



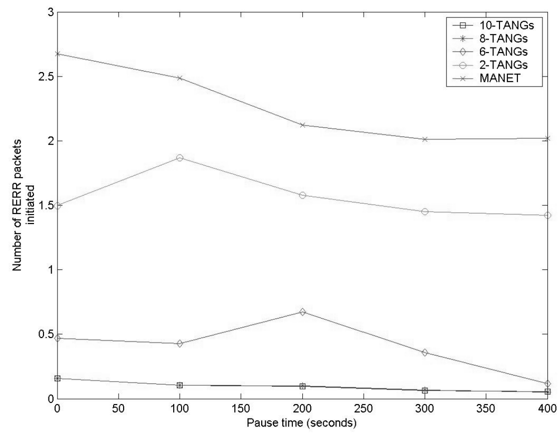


Figure 5: Number of RERR packets initiated.

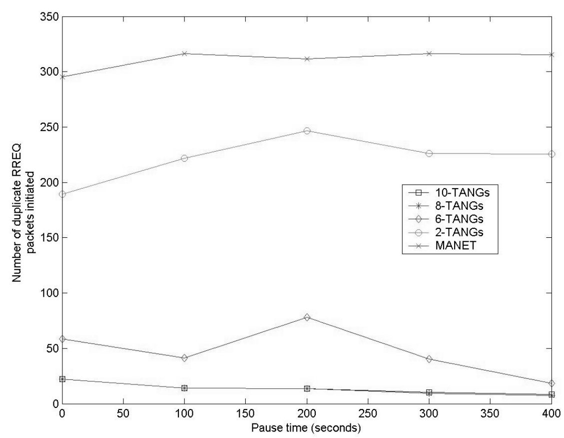


Figure 6: Number of duplicate RREQ packets initiated.

As seen in Figure 4, the packet delivery ratio of pure MANETs is very low a result of which the number of RERR messages initiated by a MANET is approximately 15 times more than infrastructured MANETs with 8 and 10 TANGs irrespective of the pause time (Figure 5). On receiving RERRs sources generate duplicate RREQ packets, which aggravate the situation further. In Figure 6, it can been seen that the number of duplicate RREQs generated in infrastructured MANETs with 6,8 and 10 TANGs is negligible when compared to pure MANETs. Due to the increased overhead (RERR and duplicate RREQ) in the network the throughput of pure MANETs is drastically affected.

D. Scalability

In these set of experiments the number of TANGs are kept fixed and chosen to be $\sqrt{n}$ where n is the number of nodes in the network [6]. Thus 10,14 and 22 TANGs are implemented in a network with 100, 200 and 500 nodes respectively. As seen in Figure 7, the throughput of an infrastructured MANET is almost constant, ranging between 0.320 – 0.328 Mbps irrespective of the pause time and number of nodes thus proving good scalability for an infrastructured MANET. The delay (Figure 8) almost doubles for 500 nodes at lower pause times and is relatively high for higher pause times too when compared to 100 and 200 nodes, but is still acceptable.

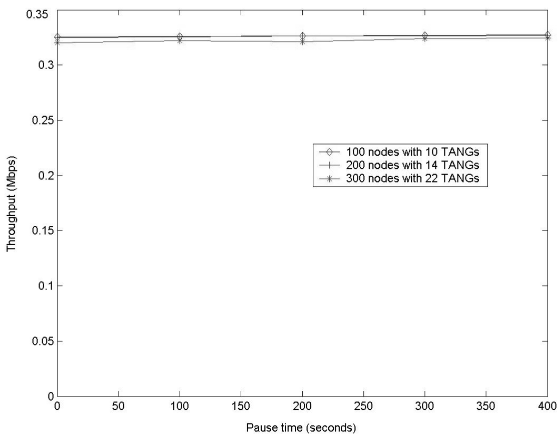


Figure 7: Throughput graph - scalability.

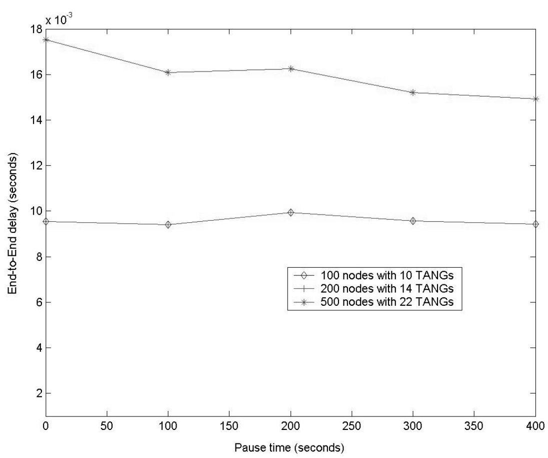


Figure 8: End-to-end delay - scalability

IV. CONCLUSION

This paper motivates the use of an infrastructured MANET as opposed to a pure MANET in order to achieve scalable network performance. A special static gateway called TANG is proposed that improves the overall performance of the network drastically. The TANGs use their short-range wireless radios to communicate with the MANET nodes and use their large bandwidth wired links to communicate among themselves, thus forming an ideally infinite backbone infrastructure. They take most of the responsibility in forwarding packets (data as well as routing packets), hence increasing the per node throughput drastically. The simulations also show that the performance of infrastructured MANETs remains almost constant even when the number of nodes is increased, indicating the stable scalability of infrastructured MANETs. The reason for such improved performance is due to the fact that TANGs break large scale MANETs into small *virtual* MANETs and hence the communication becomes *local* (over multi-hops). In addition, the source and destination that are far apart, take advantage of the backbone networks, drastically reducing the delay.

Based on this study it can be concluded that the performance of MANETs can be improved by increasing the number of TANGs up to a certain limit after which adding more TANGs to the network does not contribute significantly. In summary, the three main issues discussed in Section III were studied and from the simulation results it can be concluded that an infrastructured MANET with TANGs increase the overall performance of the MANET immensely without requiring any modification to the underlying protocol.

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