Evaluating the Effect of Fixed Infrastructure Nodes in Mobile Wireless Ad Hoc Networks

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***Abstract*—In mobile wireless ad hoc networks, there are two common issues of interest. The first issue is arise from the situation that there are not enough wireless nodes in the network. Low density of nodes results in partitioned network meaning that no route exists between some clients and their destinations destination. The second issue is that mobile clients can often only take an inefficient, roundabout route for the packet to reach its destination. These two issues can be addressed by providing *fixed infrastructure nodes*, which are immobile infrastructure nodes that generate no traffic and provide routing and forwarding services. In this report, we simulate and evaluate the effectiveness of fixed infrastructure nodes in the performance of such networks. Our simulation results show that the infrastructure nodes can increase the packet delivery ratio and coverage of network. Our results also demonstrate that a *reactive* routing protocol DSR have better performance than a *proactive* protocol DSDV.**

I. INTRODUCTION

In wireless mobile ad hoc networks, mobile clients act as routers for other clients by forwarding packets. In general, mobile clients are assumed to be free to move in any direction, and mobile ad hoc networks are assumed to have no infrastructure, such as access points or routers, assisting its operation. However, these assumptions give rise to the problem of partitioning due to the inherent randomness of such a network. In this report, the partitioning problem refers to the situation in which one group of nodes in the network become separated from other groups of nodes elsewhere in the network, possibly resulting in a lack of routes from sources to sinks.

To tackle the partitioning problem, we propose to use *fixed infrastructure nodes*. Fixed infrastructure nodes are completely immobile infrastructure nodes that only perform routing operations and do not generate any traffic. By placing fixed infrastructure nodes throughout an area, the mobile clients become much less likely to suffer from the partitioning problem, since the fixed infrastructure nodes can allow mobile clients to access a much larger coverage area, as seen in Fig. 1.

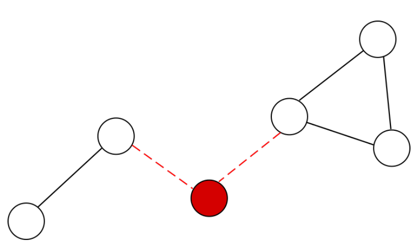

Fig. 1. A fixed node (shown in red) connecting a partitioned group of mobile clients (shown in black).

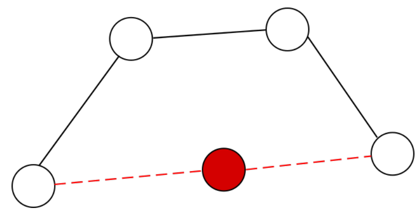

Fig. 2. A fixed node (shown in red) providing a more efficient route for mobile clients (shown in black).

Furthermore, fixed infrastructure nodes also have the potential to provide more efficient routes from the source to the destination. As the number of fixed infrastructure nodes increases, mobile clients have an increasingly high probability of sending packets along a direct path rather than a roundabout path, as seen in Fig. 2. The ability to use more efficient routes can improve the end to end latency for some specific cases. By end to end latency we mean time difference between a packet was generated at the source node and received as desired destination.

Previous works have extensively studied a similar idea in the form of wireless mesh networks [1]. In a wireless mesh network, mobile *mesh clients* route packets through immobile *mesh routers*, which behave similarly to the fixed infrastructure nodes we propose. In wireless mesh networks, mesh routers often have fixed routes to connect to one another, and also often serve as gateways to the Internet or to other networks.

However, unlike previous works on wireless mesh networks, we do not propose to use fixed infrastructure nodes as gateways. The fixed infrastructure nodes are instead only used to assist in routing for a self-contained mobile ad hoc network, and the infrastructure nodes do not have fixed connections to one another.

To validate the idea of using fixed infrastructure nodes, we use ns-3 to simulate various performance metrics of a mobile ad hoc network with infrastructure nodes.

Our results show that increasing the number of fixed infrastructure nodes improves the packet delivery ratio and throughput while having a much more variable effect on the mean latency and average hop count. Our results also show that increasing the number of mobile clients when there are fixed number of infrastructure nodes in the system, improves the throughput. It also confirms that the performance of such network is robust against an increased traffic load. Finally, our results show that using a grid geometry over a random geometry improves the packet delivery ratio specially in the case of having less number of infrastructure nodes in the network.

In next section, we describe the simulation setup and our evaluation metrics. In Section III of this report, we present our results, providing a discussion for each plot to explain . Prior work has been explained in section IV . Finally, at last section, the conclusion and future work has been presented.

II. Simulation Setup

We used the *ns-3* simulator (version 3.22) to generate our results. We simulate a set of fixed infrastructure nodes and a set of mobile clients. The set of fixed infrastructure nodes are either distributed across the simulation space according to a uniform random variable across the area or in a grid geometry. The mobile clients move across the area following the *random waypoint* mobility model with a maximal speed of 20 m/s. We considered high mobility and low mobility network by setting pause time in random waypoint model to 0 and 600 seconds [2]. To make a network partitioned, we consider a large area (300m x 1500m) and few number of mobile nodes.

At the physical layer, we adopt the propagation model according to a constant speed propagation model, in which signals travel across space at a constant speed, and the Friis propagation loss model [3]. The Friis propagation loss model is a simple propagation model that assumes that signal power is lost according to the inverse square of the distance from location to location.

At the MAC layer, we use the standard IEEE 802.11b WiFi MAC with non-QoS operation. At the application layer, we use a simple OnOff application for each mobile client. We organize the mobile clients into source/sink pairs which stay consistent throughout a simulation run, and each source sends a 64 byte packet to its sink at a rate of 4 packets per second.

We simulate two routing protocols: destination-sequenced distance-vector routing (DSDV) and dynamic source routing (DSR). DSDV is a proactive routing protocol in which each node keeps the routing table containing the next hop and distance to all other nodes in the network. On the other side DSR is an on-demand protocol in which each node tries to find a route only when it has to. We chose these two protocols too find the effect of fixed infrastructure in both proactive and reactive routing protocols.

To evaluate the network performance, we considered different metrics such as 1) throughput, 2) packet delivery ratio, 3) mean latency, and 4) average hop count of received packets. We explains each metric in the next section.

The set of parameters used in the simulation environment are given in Table 1.

TABLE I
SIMULATION PARAMETERS

Scenario Parameters	
Maximum velocity of each node	20 m/s
Dimensions of space	300m x 1500m
Transmission power	7.5 dBm
Source data pattern	4 packets/sec
Application data payload size	64 bytes/packet
MAC and PHY	IEEE 802.11b
DSR Parameters	
Maximum send buffer length	64 packets
Cache size	64 routes
Cache type	Link cache
Maximum send buffer time	30 sec
Route cache timeout	300 sec
Max # of retransmissions of route discovery	16 times
Discovery hop limit	255 hops
Max salvage count	15 times
Request period	500 ms
Max request period	10 sec
Minimal link cache lifetime	1 sec
DSDV Parameters	
Periodic update interval	15 sec
Settling time	5 sec
Max queue length	500 packets
Max queue time	30 sec
Simulation Setup	
Simulation duration	920 second
IP version	IPv4
Transport Layer Protocols	TCP
Stop transmission time	900 seconds
simulation Runs for Each Setup	10

III. Results and Evaluation

As previously stated , we evaluate the usage of fixed infrastructure nodes based on three main performance metrics along with one supplementary performance metrics. The metrics, along with how they are defined in this work, is as follows:

- *Packet Delivery Ratio*: The total number of received data packets divided by the total number of transmitted data packets during a simulation run.
- *Throughput*: The total number of bytes received divided by the total time of the simulation.
- *Mean Latency*: The average time between packet reception and packet transmission.
- *Average Hop Count*: The average number of hops a packet takes before it is received.

in this section, we want to see how these metrics vary with increasing number of fixed infrastructure nodes while the number of clients is fixed. The second step is to fix number of infrastructure nodes and change the number of mobile clients that are actually generating traffics. We are also interested in both low mobility networks and high mobility ones so we simulated the results for the case that mobile node's pause time is either 0 or 600 seconds. At last, we want to show how deployed location of infrastructure nodes change packet delivery ratio. For that, we consider randomly located fixed nodes and grid structure.

A. Effect of Increasing Number of Fixed Infrastructure Nodes

In the simulations for this scenario, we setup the simulation with the parameters described in Section II. We vary the number of fixed infrastructure nodes from 0 to 30 while maintaining the number of mobile clients to 20, comprised of 10 source-sink pairs. We also place the fixed infrastructure nodes randomly. We examine a high mobility scenario, with

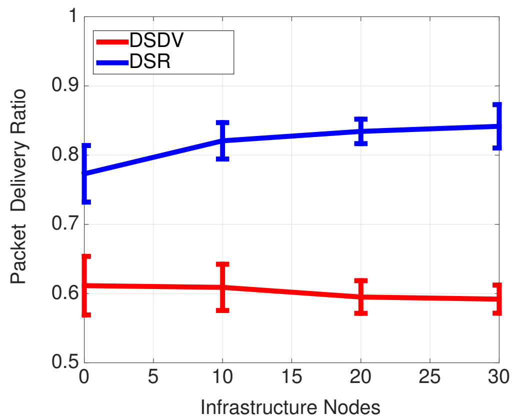

Fig. 3. Packet delivery ratio in high mobility (0 seconds pause time) environment as a function of infrastructure nodes number.

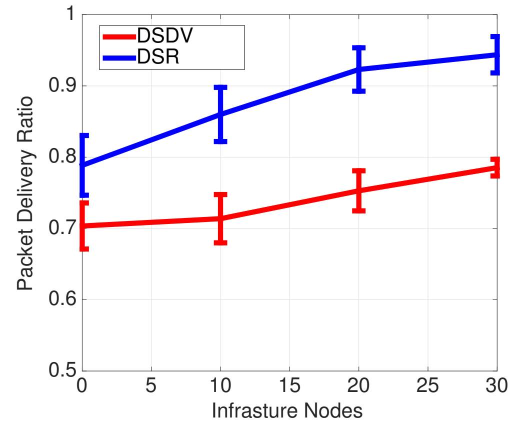

Fig. 4. Packet delivery ratio with low mobility (600 seconds pause time) environment as a function of infrastructure nodes number.

zero pause time, and a lower mobility scenario, with a 600 second pause time. The routing protocols examined are DSR and DSDV.

1) Packet Delivery Ratio: In Fig. 3, we plot the packet delivery ratio with 0 pause time, and in Fig. 4, with 600 pause time.

As we can see from Fig. 3, increasing the number of fixed nodes from 0 to 30 nodes improves the packet delivery ratio by 7% for DSR. And packet delivery ratio is almost constant for DSDV when there is zero pause time. The main reason is that DSDV does not updates its routing tables fast enough [1] in such high mobility environment. Thus the main reason for packets loss is that the previous route is now out-of-date and no longer valid. When the pause time is increased to 600 seconds, increasing from 0 to 30 fixed infrastructure nodes improves the packet delivery ratio by 15% for DSR and 8% for DSDV. Here by having 30 infrastructure nodes ,the packet delivery ratio of DSR is almost one. It is worth mentioning that in low mobility network, the packet delivery ration is higher for both DSDV and DSR in compare to high mobility case.

Unsurprisingly, increasing the number of fixed infrastructure nodes improves the packet delivery ratio of DSR, regardless of pause time. The improvement can be explained by considering the partitioning problem as mentioned in the introduction. As the number of fixed nodes increases, it becomes far less likely for nodes to become isolated because a greater area is covered. The greater coverage increases the probability that a route exists between source and destination, which then improves the packet delivery ratio.

However, we can see that increasing the number of fixed infrastructure nodes does not improve the packet delivery ratio of DSDV at zero pause time, even though the coverage improves. To explain the lack of improvement with DSDV at zero pause time, we note that the mobile clients move without pause, and the routing tables update only every 15 seconds. The movement of mobile clients breaks previously valid routes, causing the routing table to become out-of-date. The main source of error is therefore not the lack of a route towards the destination, but rather the out-of-date routing tables that are used, which means that the improved coverage has a much smaller effect.

DSR does not suffer from the same loss of performance at zero pause time because DSR is reactive. When using DSR, if a source discovers that a route is no longer valid, it will attempt to discover a new route to the destination, which is something that DSDV does not do. In DSR, if a source node finds out that the route in its cache to a particular destination is out of dated, it will start route discovery by broadcasting route request.

When increasing the pause time of the same simulation to 600 seconds, we see that increasing the number of fixed infrastructure nodes does in fact improve the packet delivery ratio of DSDV. When pause times are higher, the situation in which the routing tables are out-of-date becomes much less likely. The partitioning problem thus becomes the main source of dropped packets for DSDV with high pause time, allowing fixed infrastructure nodes to noticeably improve the packet delivery ratio of the network.

2) Mean Latency and Average Hop Count: In Fig. 5 and 6, we find the mean latency and average hop count as a function of the number of fixed infrastructure nodes for low mobility case. As mentioned earlier by latency, we mean the time difference between when a packet is generated and is successfully received to its desired destination. In these plots, we see that, when going from 0 to 30 fixed infrastructure nodes, the mean latency decreases by 55 *ms*, and the average hop count is increased by 8.9 % for DSR, while the mean latency increase by 18 *ms* and the average hop count is decreased by 19.4 % for DSDV.

Surprisingly, we find that for DSR average hop count is increasing wile latency is decreasing and on the other side for DSDV average hop count is decreasing while latency is increasing. It seems like a contrary conclusion to our earlier hypothesis that infrastructure nodes providing us with more efficient routes (less hops) and so that packets can be delivered

[1] In simulation, DSDV updates periodically every 15 seconds.

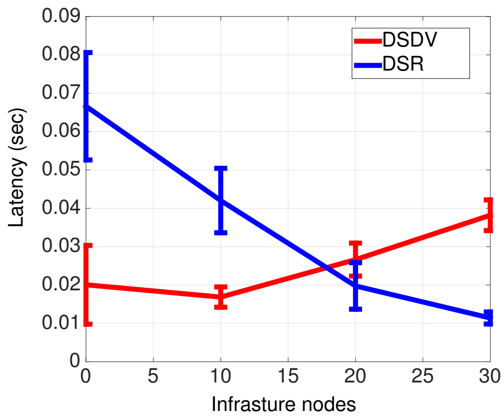

Fig. 5. Mean Latency in low mobility (600 seconds pause time) environment as a function of infrastructure nodes number.

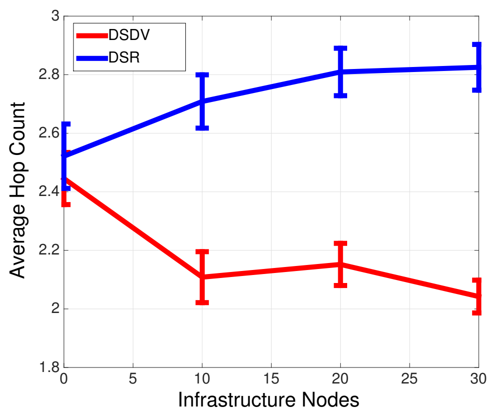

Fig. 6. Average hop count with low mobility (600 seconds pause time) environment as a function of infrastructure nodes number.

with less latency.

These unexpected results can be explained by realizing that the fixed infrastructure nodes have several opposing effects on the mean latency. First, fixed infrastructure nodes can improve the latency by providing more efficient hops from source to destination, as shown in the introduction of this paper and in Fig. 2. This effect decreases the mean latency and the average hop count.

Second, fixed infrastructure nodes also prevent the partitioning scenario from occurring, as noted in the previous section. When a network is partitioned, mobile clients can only communicate with users that are nearby to itself, while packets sent to destinations in the separated partition are dropped. Packets sent to separated partitions would have needed to travel a longer distance and take routes with higher hop counts, but since they are dropped, the mean latency and average hop count actually improves.

When fixed infrastructure nodes are added, there are fewer partitions. The packets that would have been dropped are instead successfully received with higher hop counts and longer latency, adding to the mean latency and average hop count.

Third, fixed infrastructure nodes add to the routing overhead of DSDV and, to a lesser degree, DSR. When increasing the number of fixed infrastructure nodes, routing table updates and route discoveries take more time because they require a response from a greater number of nodes. Therefore, the mean latency increases with this effect.

The combination of these three effects results in the mean latency plot and average hop count plot seen in Fig. 5 and Fig. 6, in which we do not see dicreasement of mean latency and average hop count. As explained earlier, this does not invalidate our earlier hypothesis that fixed infrastructure nodes can provide more efficient routes from source to destination. The routes that would have existed without fixed infrastructure nodes become more efficient with lower latency, but routes that would not have existed have a higher hop count and end-to-end latency.

B. *Effect of Increasing Number of Mobile Nodes*

In the simulations for this scenario, we setup the simulation with the parameters described in Section II. We vary the number of mobile client nodes from 10 to 30 while maintaining the number of fixed infrastructure nodes to 20. The fixed infrastructure nodes follow a random placement. We examine a high mobility scenario, with zero pause time. The routing protocols examined are DSR and DSDV.

The goal of examining the effect of increasing the number of mobile client nodes is to confirm that the usage of fixed infrastructure nodes does not hinder the network as more traffic generating mobile clients enter the network. The following plots are meant to show that the usage of fixed infrastructure nodes is robust against increasing mobile traffic.

1) Packet Delivery Ratio and Throughput: In Fig. 7 and 8, we examine the packet delivery ratio and throughput respectively as a function of the number of mobile clients. As we can see from Fig. 7, packet delivery ratio is almost constant for DSR and drops by 8% for DSDV. In Fig. 8, we see that going from 10 mobile nodes to 30 mobile nodes increases the throughput by 189.23 % for DSR and 167.3% for DSDV.

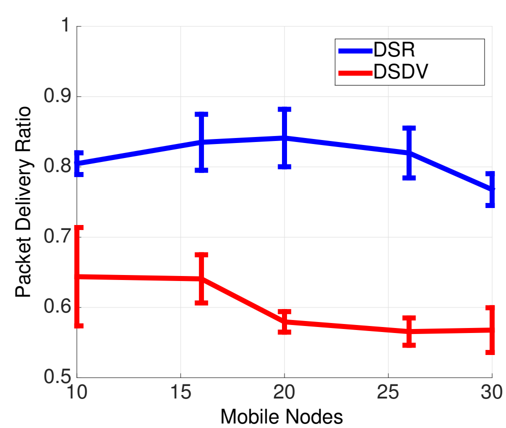

Fig. 7. Packet delivery ratio as a function of mobile nodes number.

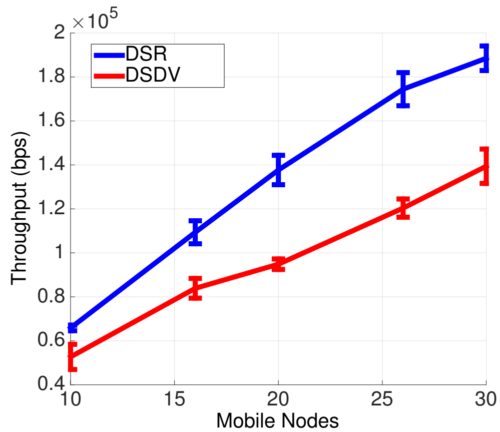

Fig. 8. Throughput as a function of mobile nodes number.

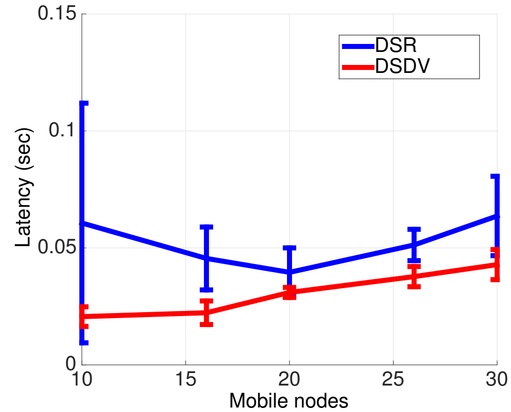

Fig. 9. Mean Latency as a function of mobile nodes number.

The packet delivery ratio plot can be explained through the fact that packet delivery ratio experiences two opposing forces as the number of mobile clients increases. As the number of mobile clients increases, the coverage and the likelihood of a valid route to the destination improves. However, each mobile client generates 4 packets per second so as the number of mobile clients increases, there is also a greater likelihood of collision. These two forces counteract each other to result in the plot seen in Fig. 7. For DSR, we can see that by increasing 10 mobile clients to 20, the packet delivery ratio is improved because the weight of the first force is higher. But if we continue on increasing number of mobile nodes or traffic in the network, the weight of collisions will cause packet delivery ratio degradation.

DSDV has a much poorer packet delivery ratio than DSR for reasons similar to the previous plot with increasing number of fixed infrastructure nodes. The packet delivery ratio suffers from the fact that it is a high mobility environment with infrequent routing table updates. DSR, again similar to the previous plot, does not suffer from the routing table update problem because its on demand nature and is instead reactive.

The throughput, on the other hand, is relatively straightforward. As the number of mobile clients increases, more traffic is generated, causing the sum throughput of the network to increase. The increase is somewhat concave because as the number of mobile clients increases, there is also a greater likelihood of collision and dropped packets, offsetting the improvement from the greater amounts of generated traffic. This explains the results seen in Fig. 9.

DSDV has a much poorer throughput compared to DSR for the same reason above. The infrequent routing table updates combined with the high mobility environment causes more packets to attempt to take an invalid path, increasing the number of dropped packets and decreasing the throughput.

Both these plots confirm the fact that the usage of fixed infrastructure nodes is almost robust against increasing numbers of traffic generating mobile clients.

2) Mean Latency and Average Hop Count: We examine the latency and average hop count as a function of the number of

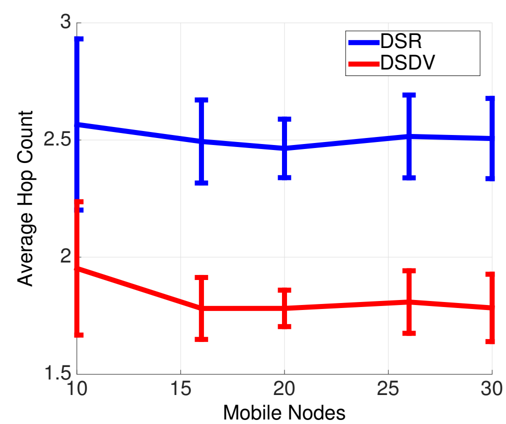

Fig. 10. Average hop count as a function of mobile nodes number.

mobile clients in Fig. 9 and Fig 10 respectively. Based on this results we can see that both metrics remains almost constant for DSDV and DSR by increasing number of mobile clients in the network.

In this scenario, there are four effects on the mean latency. The first, second, and third effect are the same as previously stated for the increasing number of fixed nodes. The first is that there are more efficient hops for pre-existing routes due to increased coverage, decreasing the average number of hops; the second is that there is a lower likelihood of a partitioning event, which causes an increase in the average number of hops; and the third is that the routing overhead from increased numbers of nodes hurts latency.

However, there is an additional fourth effect, which is that the increased amount of traffic causes the network to become congested. There are additional source/sink pairs, each of which generate its own traffic. Packets are increasingly likely to be forced to wait as other data streams use the spectrum space, increasing the mean latency.

The combination of these four effects explains why the latency for DSR decreases first and then increases. Most of the time these factors cancel out each and we see an almost constant behavior.

C. Effect of Geometry of Fixed Infrastructure Nodes

For the simulations in which we examine geometry, we look at the case where fixed infrastructure nodes are placed according to a grid geometry. We fix the number of mobile clients to 20, with 10 source/sink pairs, and we simulate for 10 and 30 fixed infrastructure nodes. The grid geometry is according to the following: for the 10 fixed infrastructure node simulation, they are placed in a 2×5 grid; and for 40, they are placed in a 5×6 grid. The grid geometry is compared to the scenario in which fixed infrastructure nodes are randomly placed in the simulation space.

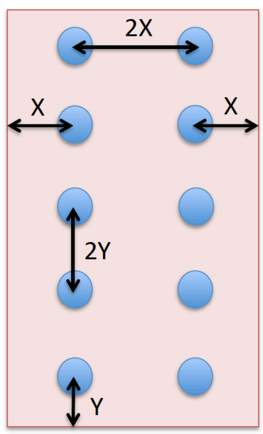

Fig. 11. An example for a deployment of 30 infrastructure nodes of a 6 × 5.

The goal of this simulation is to examine how intelligent, coverage-maximizing fixed node placement can affect the performance of networks. The random fixed node placement simulation therefore represents the real-life scenario in which obstacles and geography do not allow us to deploy fixed infrastructure nodes in certain positions. The grid geometry simulation represents the best case, coverage maximizing fixed infrastructure node placement.

1) Packet Delivery Ratio and Throughput: In Fig. 12 and Fig. 13, we examine the packet delivery ratio and the throughput respectively with DSR and DSDV. We find that the grid scenario improves the packet delivery ratio over the random placement scenario with 10 total fixed infrastructure nodes by 15 % for DSR and 17 % for DSDV, and improves the packet delivery ratio over the random placement scenario with 30 fixed nodes by 2 % for DSR and 3 % for DSDV.

As expected, the grid placement of fixed infrastructure nodes outperforms the random placement of fixed infrastructure nodes for DSR and DSDV because the grid placement maximizes the coverage and is best at minimizing the probability of network partitioning.

The percentage by which the grid placement outperforms the random placement decreases as the number of fixed nodes increases. This percentage decreases because the network

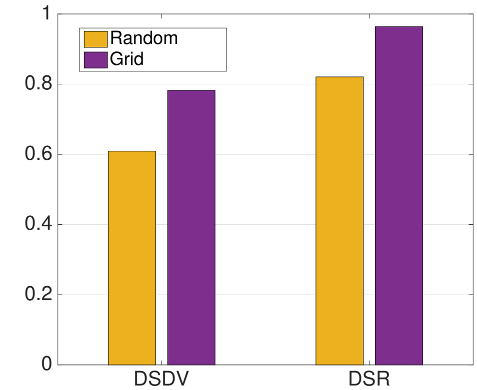

Fig. 12. Packet delivery ratio with 10 infrastructure nodes placed randomly or in grid.

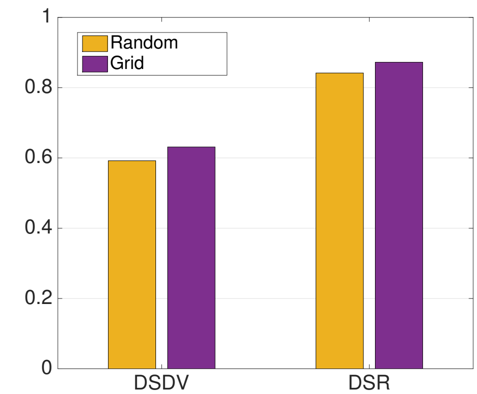

Fig. 13. Packet delivery ratio with 30 infrastructure nodes placed randomly or in grid.

asymptotically approaches the zero lower bound for partitioning probability. When the network has so many fixed infrastructure nodes, the coverage spans the entire simulation space and there is zero probability for a partitioning event. When this happens, adding an additional fixed infrastructure node does not improve the packet delivery ratio or throughput of the network since there are no dropped packets due to lack of a route. Meanwhile, adding fixed nodes continues to improve the packet delivery ratio of the random placement scenario because the probability of a partitioning event does not reach zero and the coverage is not assured to span the entire simulation space. It is worth mentioning that the performance of network using random located infrastructure nodes is better than performance of DSDV even with grid structure of fixed nodes.

IV. Related Work

The initial study of relay channels, which is what multi-hop wireless networks utilize, can be traced back to 1970s [4] [5] [6]. Most subsequent works were focused on the information theoretic capacity of a network that has relay nodes. For example the capacity of the relay channel consisting of single source, destination and relay station was derived by Cover and El Gamal in [7].

In [8] and [9], authors show that the throughput that can be achieved in an ad hoc network is on the order of

$$\mathcal{O}\left(\frac{1}{\sqrt{K}}\right),$$

where K is the number of nodes in the network. Another important implication provided in [9] is that relaying nodes can add the throughput of an ad hoc network.

The wireless mesh network idea has been extensively studied from the perspectives of the MAC layer [10]–[12], routing layer [13]–[16] and the TCP layer [17], [18].

Several previous works [19]–[21] have characterized the influence of protocols on ad hoc networks without fixed infrastructure nodes using *ns-2*. To the best of our knowledge, there is no previous work with a similar characterization with fixed infrastructure nodes.

V. Future Work

Our work is an initial study on the effect of fixed infrastructure nodes on a mobile wireless ad hoc network using existing routing protocols, such as DSR and DSDV. However, as an initial study, additional simulations examining the effect of increasing the number of mobile clients with different numbers of fixed nodes will be particularly insightful to see how varying numbers of fixed infrastructure nodes behave when placed under increased traffic load.

Additionally, there is one additional advantage of fixed infrastructure nodes that has not been taken into account in this work. Fixed infrastructure nodes, by virtue of being part of the infrastructure, usually have a fixed, less easily interrupted power source, and are much less likely to be randomly turned off. These advantages make fixed infrastructure nodes much more reliable than their mobile client counterparts.

As a by-product of our analysis, we find DSR, a reactive routing protocols, demonstrate a better performance than the proactive routing protocols.

Finally, the most interesting direction to take this work is to develop routing protocols that are designed to take advantage of fixed infrastructure nodes. The routing protocols can be designed so that nodes, mobile or client, preferentially choose fixed infrastructure nodes over mobile client nodes in their routes towards their destinations. This will improve link reliability and increase packet delivery ratio. In future, we want to modify DSR so that each node can find the most reliable routes for sending each data packet when more than one route exits from source to destination.

VI. Conclusions

This report has presented an evaluation of the effects of fixed infrastructure nodes, which are immobile infrastructure nodes that perform routing operations but do not generate traffic, in mobile ad hoc networks. Fixed infrastructure nodes provide additional coverage to minimize the probability of a partitioning event, in which certain groups of nodes are completely disconnected from other groups of nodes. Fixed infrastructure nodes also provide more efficient hops for some nodes to take to their destinations. These two advantages improve the packet delivery ratio and the throughput of the system, while having an ambiguous effect on the mean latency and average hop count of the system.

In our evaluation, we examined the packet delivery ratio, throughput, latency, and average hop count of the network. We found that increasing the number of fixed nodes improves the packet delivery ratio and throughput and has a complicated effect on latency and average hop counts. We also showed that low mobility and high mobility networks behave differently by adding infrastructure nodes.We also found that networks with fixed infrastructure nodes are also robust against increasing amounts of traffic. Finally, we determined the effect of using a grid-geometry for fixed infrastructure nodes over a random geometry specially in the case of having less number of infrastructure nodes in the network..

We conclude that fixed infrastructure nodes can be an immensely helpful for improving the performance of a mobile ad hoc network, especially if the main goal is to improve the reliability and throughput of the network.

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