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Geometric Sequence Based Multipath Routing Protocol for Multi-hop Ad hoc Networks

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Purpose- Ad hoc networks have increased in usage and popularity in both research and deployment. Packet routing in ad hoc networks is a very important factor to the successful operation of the network. Recently, sending the data packets over more than one path that are available between the sender and the receiver become an attractive approach in routing. In this work, a new approach for distributing packets, over the available paths, called Geometric Multipath Load Balancing routing protocol (GMRP) is proposed.

Design/methodology/approach- GMRP distributes packets according to the geometric sequence. GMRP is evaluated using GloMoSim simulator. We use packet delivery ratio and end to end delay as the comparison performance metrics. We also vary many network configuration parameters such as number of nodes, transmission rate, mobility speed, and network area.

Findings- The simulation results show that GMRP reduces the average end-to-end delay by up to 49% and increases the delivery ratio by up to 8%.

Originality/value- This study is the first to propose to use geometric sequence in the multipath routing approach.

Keywords: congestion control;load balancing;multipath;Fibonacci sequence;geometric sequence

1. Introduction

Ad hoc networks have increased in usage and popularity in both research and deployment. An ad hoc network consist of a set wireless nodes that are usually mobile. These ad hoc networks with mobile nodes are usually called Mobile Ad hoc NETworks (MANET). MANET elements are flexible in nature. Every mobile node can communicate directly with close-by nodes without any pre-existence of a central administration or infrastructure, which make MANETs easy to be configured. Also, the network topology can change dynamically because of node mobility which may cause changes in the current routes between nodes. Dynamic topology, unstable links, constrained bandwidth, limited energy capacity, and the absence of fixed infrastructure are special features of MANETs. MANETs are used in many areas and applications such as emergency situations in which existing infrastructure is damaged. Moreover, before a node can send data packets to another node, it should make sure the there is a route between the sender and the receiver. The route may use the nodes in-between the sender and the receiver if the sender and the receiver are not in communication range. This route style is called multi-hop route. Each node on the rout can act not only as host, but also as a router to help discover and maintain routes to other nodes (Adhyaru & Patel (2013), Jain et al. (2012)). Packet routing in MANETs is a very important factor to the successful operation of the network (Mauve et al. (2001), Zou et al. (2002), Chitkara & Ahmad (2014), Khanfar (2015)). Routing is responsible for finding all the paths between any sender and receiver in the network and route the data packets over the best paths of all these paths. It is also responsible for maintaining the connection between a sender and a receiver in the case that the best path got broken. Routing is one of the most challenging problem in MANETS due to the following reasons.

- bf Mobility. There is no fixed infrastructure or topology in MANETs because it consists of a set of nodes that are usually moving continuously with different speed and directions, and these nodes connect to each other without the need for any intermediate devices such as a base station. Node movements may cause nodes to go out of range of each other, which in turn may cause some route breaking. This usually leads to packet dropping or delay (Aarti (2013)).
- **No Infrastructure.** Because there is no base station to control the operations in the network, the nodes themselves should collaborate with each other to manage the functionality of the network such as addressing, location of nodes, routing, which includes routes discovery process and route maintenance process, and power control(Chitkara & Ahmad (2014), Aarti (2013)).
- **Limited Security.** In MANETs, nodes connect to each other using wireless links, which makes them more vulnerable to threats and attacks (Aarti (2013)). Attacks are related to some issues such as integrity, authenticity, availability and confidentiality (Aarti (2013)). Any node can easily be connected to the network without requiring an authentication process. Some factors must be taken into account when building routing protocol to avoid the security problems.
- **Limited Link Capacity.** Wireless links usually has less capacity than wired links in infrastructure networks. The throughput of the wireless network is lower especially if the wireless links suffer from fading, multiple access, interference, and noise. Also, congestion problem can be increased with limited bandwidth (Aarti (2013)).
- **Multi-hopping.** If one node requires sending packet to another node outside its transmission range, then it needs to forward the packet to one or more intermediate nodes to reach the specific destination. This may cause

queuing of the packets at the intermediate nodes and also may lead to quick battery consumption of these intermediate node.

- **Limited Energy.** Mobile nodes are usually powered by batteries with limited capacity. Energy is consumed when a mobile node sends or receives packets, and also when it stays idle listening to the wireless medium for any possible communication requests from other nodes. When the battery is fully discharged, it is usually hard to recharge or replace. Power failure of a mobile node affects not only the node itself, but also all other nodes that use this node as an intermediate node. To solve this problem, it is required to have well-designed energy efficient routing protocols (Jain et al. (2012), Aarti (2013)).

Recently, sending the data packets over more than one path between the sender and the receiver, simultaneously, become an attractive approach in routing to face the previously mentioned challenges (Adhyaru & Patel (2013), Singh et al. (2014), Tashtoush et al. (2014), ilker Basaran & Molle (n.d.), Ahn et al. (2010), Zangeneh & Mohammadi (2012), Sambasivam et al. (2004), Javan & Dehghan (2007), Haboush et al. (2012), Jain et al. (2012)). The main benefits of distributing the data packet over multiple paths are, (1) load balancing over all nodes which achieves more resource utilization, (2) the congestion problem over the best path is reduced (3) maintaining the connection between the sender and the receiver becomes easier because if best path is broken, the sender uses the other paths directly, and (4) power consumption of the nodes that are along the best path is reduced which increases the battery life of these nodes.

In this paper, a new approach called Geometric Sequence Based Multipath Routing Protocol (GMRP) is proposed. GMRP distributes packets over the available paths between the sender and the receiver according to the geometric sequence. Paths that have more hops are assigned less packets. GMRP is based on the well-known Ad hoc On-Demand Distance Vector (AODV) routing protocol (Perkins et al. (2003)) to discover and maintain the paths.

GMRP is evaluated using GloMoSim simulator version 2.03. We compare the performance of GMRP with the AODV and another load balancing protocol that is recently proposed and known as Fibonacci Sequence Based Multipath Routing Protocol (FMRP). We use packet delivery ratio and end to end delay as the comparison performance metrics. We also vary many network configuration parameters such as number of nodes, transmission rate, mobility speed, and network area. The simulation results show that GMRP outperforms both FMRP and AODV routing protocols under all scenarios. GMRP reduces the average end-to-end delay up to 42% when compared to FMRP and up to 49% when compared to AODV. Also it increases the deliver ratio by up to 4% when compared to FMRP and by up to 8% when compared to AODV. The results show that the proposed scheme is feasible and efficient to implement in ad hoc networks.

The rest of this paper is organized as follows. In Section 2, some background information is presented and Section 3 summarizes some related work. The proposed protocol is explained in Section 4. Next, Section 5 presents the evaluation methodology and the simulation results are presented in Section 6. Finally, the conclusions and future works are summarized in Section 7.

2. Background Information

2.1. *Ad Hoc on-Demand Distance Vector (AODV) Routing Protocol*

AODV roting protocol is one of the most used routing protocols in ad hoc networks. It decreases the number of packets broadcasted in the network because it builds a route only on demand. Each node keeps a routing table with an entry of each route destination. The entries that are kept in the table are just for the nodes that participated in the recent route building process. This means that the routes are not recently used, expire and are deleted from the routing tables. AODV does not have any central organization model to control routing process. Therefore, it depends on other intermediate nodes to save the information needed in the routing tables and keep this information until its expiration time. This process is known as hop-by-hop routing process. Another important feature in AODV is that it supports unicast, multicast and broadcast communication (Khanfar (2015)). AODV also avoid count to infinity problem (also known as free loop protocol) by using the destination sequence number (Sharma & Singh (n.d.)). An intermediate node can send a reply to the source if it has a route to the destination, otherwise, it acquires the destination sequence number from the request and store it in its routing table (Sharma & Singh (n.d.)). AODV has two procedures: route discovery process and route maintenance process.

2.1.1. *Route Discovery Process*

If a node has data packets and needs to send them to a specific receiver, it checks if there exists a route entry in its routing table for this receiver. If an entry is found, the sender starts sending its data packets directly. Otherwise, it initiates a discovery process. The source node broadcasts a Route Request Packet (RREQ) to its direct neighbors. The RREQ packet contains the source-address, the source-sequence number, the destination-address, the destination-sequence number, the broadcast id, and the hop-count. This process continues until RREQ packet reaches the destination which sends the Route Reply Packet (RREP) back to the source (Sharma & Singh (n.d.), Patil (2012)). Every RREQ packet carry time-to-live (TTL) information and a node does not broadcast the RREQ if this timer is expired. If the source node does not receive an RREP packet for its RREQ in a specific period of time, the source rebroadcast a new RREQ with a larger TTL value. The Source node set TTL to higher value to grantee that the RREQ reaches every node in the network (Khanfar (2015)).

2.1.2. *Route Maintenance Process*

If any link along a path breaks, the active nodes that belong to this link try to find any alternative path to the same destination. If they cannot have any other path, they flood a Route Error packet (RERR) in the whole network so that the RERR packet reaches the source. After that, if the source still needs the route, it re-initiates the discovery process (Sharma & Singh (n.d.)).

2.2. *GloMoSim Simulator*

GloMoSim[a] is a mobile wireless network simulator used to simulate the behavior and study the performance of the routing protocols under different network environments. It is a discrete event simulator that is written in C. GloMoSim stands for Global Mobile Information System Simulator built over PARSEC which is also a scalable simulator that can simulate wireless networks with thousands of mobile nodes (Jaiswal & Prakash (2014)). GloMoSim is designed to simulate the OSI network architecture. It consists of seven layers. Each layer works as an independent module. Any change occurs in one layer dose not affect the other layers. Moreover, the interaction between these layers can be done using simple Application Programming Interfaces (APIs) as shown in Figure 1. These APIs help GloMoSim users to change features without taking into account what happen inside the simulator (Umashankar (2014)). This flexibility makes GloMoSim easy to use and appropriate for designing new protocols. It is also preferable for networking research and education. In our experiment we focus only in the network/routing layer which implement the routing process.

3. Related work

In this section, we summarize the most related work to the work in this paper. Mainly, we summarize the related work done in the multipath routing approach.

The work by (Ahn et al. (2010), Zangeneh & Mohammadi (2012)) have proposed a new multipath routing protocol called Multipath Node-disjoint with backup List AODV (MNL-AODV) that is based on AODV. The protocol build another path that is called the back-up path, in addition to the AODV single shortest path between the same source and destination. These paths are node-disjoint paths, which means that there are no common nodes in the two paths. The backup path was only used when the primary path became invalid. This approach mainly decreases the end-to-end delay because no re-initiation processes is needed in the case that the shortest path got broken.

The work by (Sambasivam et al. (2004)) identify multiple paths during the route discovery process. Each path is maintained using the unicast periodic update packets. The goal of these packets is computing the signal strength for each hop

[a] `http://pcl.cs.ucla.edu/projects/glomosim/GloMoSimManual.html`

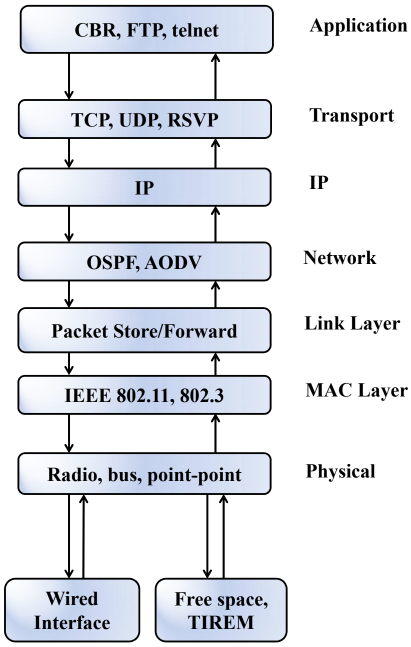


Fig. 1: The layered Approach and models supported at each layer in GloMoSim

along the alternative paths. The proposed algorithm in this work selects the paths that has the highest signal strength for packet transmission.

The work by Javan & Dehghan (2007) show that some MANETs multipath routing protocols, that distribute data packets over the available node-disjoint different routes simultaneously, suffer from some medium overlapping between routes. That is because even if two paths does not share any common nodes, some nodes that belong to the two different paths may be close to each others which make them share the same medium. Thus, sending data packets through a path affects the other paths even if they are node-disjoint paths. To solve this problem, the authors proposed a new multipath routing algorithm that detects an uses zone-disjoint routes between any source and destination. Their simulation results show that their proposed algorithm increases the data delivery ratio and minimizes the average end to end delay in the network.

Haboush et al. (2012) proposed a routing protocol called multiple node disjoint paths protocol (MNDP). The main idea of this protocol is to find multiple paths during the discovery process, and distribute the data packets over these paths linearly with sending more packets on the shorter paths. If the routing table stores two or more routes with the same number of hops, it consider the recency of the path and send more packets on the more recent path. This approach achieves load balancing and reduces congestion over the shortest path.

Tashtoush et al. (2014) build an effective multipath routing protocol, that we call it Fibonacci Sequence Multipath Routing Protocol (FMRP) here, that distributes packets over the available paths according to the Fibonacci sequence. This routing protocol distributes the sent packets over at the best seven available paths. Of these paths, the path with more hops is assigned less number of data packets. The following steps illustrate the procedure that the FMRP go through to build establish a multihop connection between the sender S and destination D in the network shown in Figure 2. Circles in the figure represent nodes and lines represent direct wireless connection.

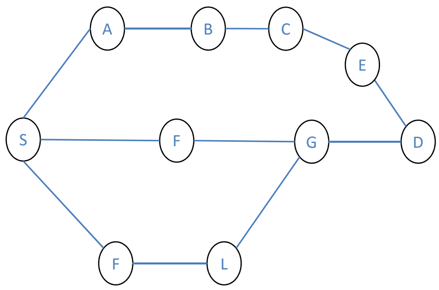


Fig. 2: Multiple paths between source and destination

- The FMRP protocol discover the availability of the three paths between S and D, {S, A, B, C, E, D} with five hops, {S, F, G, D} with three hops, and {S, H, J, G, D} with four hops.
- All these three paths are recorded in the routing table of S in increasing order according to the hop count.
- The longest path, {S, A, B, C, E, D}, is the first path with five hops. This path takes the lowest number (first number in the Fibonacci sequence) of the sent data packets. The shortest path, {S, F, G, D} comes the third in the table with three hops. This path takes the highest number (third number in the Fibonacci sequence) of the sent data packets.
- In the case that two routes or more have the same number of hops, these paths are sorted according to their age. The more recent route is placed after the oldest in the routing table.

4. The Geometric Sequence Based Multipath Routing Protocol (GMRP)

In this paper, we propose a new multipath routing protocol for multihop communication in ad hock networks. The new protocol is built over AODV to find the paths and build the routing tables, and distributes the sent packets over the N shortest paths instead of only sending all packets over the shortest path. To distribute the packets over the best N shortest paths, we used the first N numbers from the Geometric Sequence, where we use the higher numbers on the shorter paths. In the Geometric series, the n_{th} element is calculated using Equation 1 and fist N elements are as shown in Equation 2. The terms a and r are the first element in the series and the common ratio respectively.

$$x_n = a * r^{(n-1)}, n = 1, 2, 3, ..., N \quad (1)$$

$$a, ar, ar^2, ar^3, ar^4, ar^5, ..., ar^N \quad (2)$$

Figure 3 shows a Geometric Sequence packet distribution example over the available 4 shortest paths between the sender S and the destination D. There is the path {S, F, K, L, M,D} that has 5 hops, the path {S,A,B,C,D} that has 4 hops, the path {S, J, H} that has 3 hops, and the path {S, E, D} that has 2 hops. In this example, a is 1 and r is 2. The black rectangles, in the figure, represent the packets that are being sent over a path.

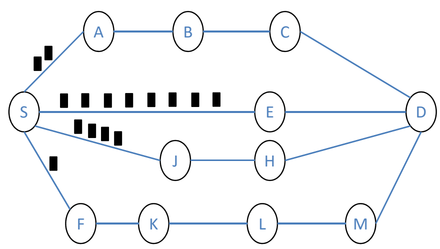


Fig. 3: Multiple paths between source and destination

In this paper, we compare our work with the previous work by Tashtoush et al. (2014). In that paper, the authors proposed a multipath routing protocol that distribute the data packet to be sent over the N shortest paths according to the first N numbers in the Fibonacci sequence. The Fibonacci sequence is shown in Equation 3. We also compare our algorithm with a basic algorithm that uses the linear series shown in Equation 4. In this equation, a is the first term and b is difference between each two concentrative terms in the series.

$$f(n) = \begin{cases} 0 & n = 0 \\ 1 & n = 1 \\ f(n-1) + f(n-2) & n > 1 \end{cases} \tag{3}$$

$$X_n = a + (n-1) * b, forn = 1, 2, 3, ..., N \tag{4}$$

By studying the linear, the Fibonacci, and the Geometric series statistically, the Geometric Sequence with r = 2 and a = 2 is found to be the fastest to get larger terms. For example, by considering the first 20 terms of these three series, we find that the Geometric series provided larger numbers on the shorter paths. These results are shown in Figure 4. Figure 5 shows a case study of distributing the

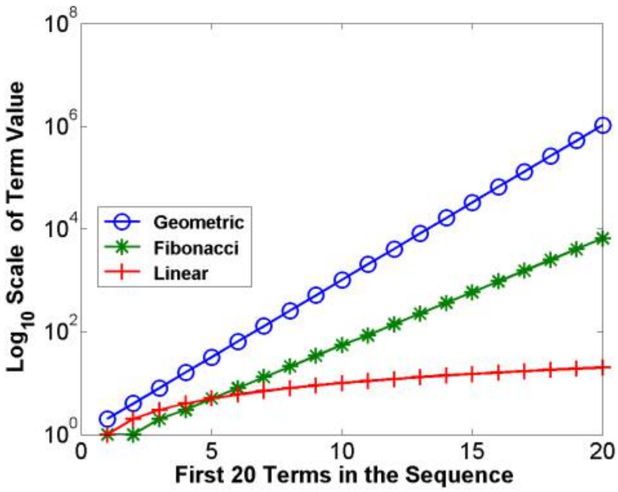


Fig. 4: Comparison between Geometric, Fibonacci and Linear sequence over the first 20 terms of sequence

packet that are being sent over 10 of the available paths. Lower sequence numbers are used for longer paths. As can be seen from the Figure, half of the data packets are sent over the shortest path and only 0.1% of the the packets are sent on the longest path. Furthermore, we can see clearly that almost 75% of the data packets are being sent over the two shortest paths. With the Fibonacci sequence, the data packets are spread more fairly over the available paths and the Linear series was the fairest among the three. We can see only 38% of the data packet are sent over the shortest path and 0.7 % are sent over the longest path with the Fibonacci series.

While with the Linear series, the numbers are 18% over the shortest path and 1.8% over the longest path.

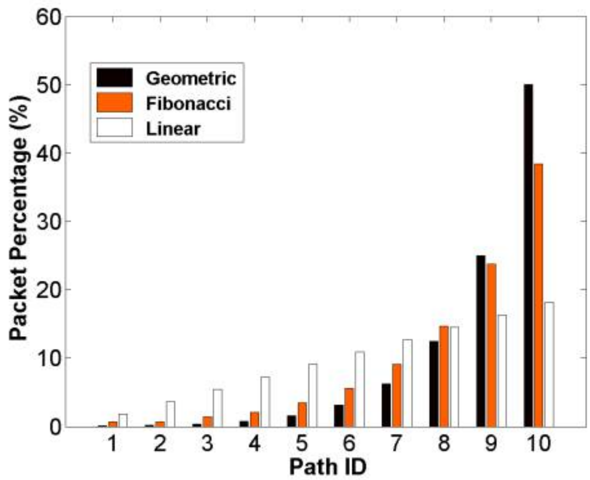


Fig. 5: Comparison between Geometric, Fibonacci and Linear sequence in one case study

5. Evaluation Methodology

To evaluate the proposed protocol, we implement it in GloMoSim. We also implement FMRP and AODV in the simulator to compare their performance with the proposed protocol performance. We use the following performance metrics in our experiments:

- Packet Delivery Ratio (PDR): It is a measurement of the efficiency of routing protocols. It is computed as the ratio of the number of data packets successfully received by the destination to the number of data packets sent by the application layer of the source. Assuming that a source node sends 100 data packets to a destination, and the number of data packets successfully received by the destination is 60, we say that the data delivery ratio is 60%. PDR gives an idea on how many packets are to be retransmitted because they are being lost. Packet retransmission reduces the network bandwidth and battery-power utilization.
- Average End-to-End delay: The average time that is required for a sent packet to arrive at the destination. This delay includes the route discovery process delay, propagation delay and packet processing delay. It is computed by subtracting the time at which the first data packet was sent by source from the time at which it reaches the destination.

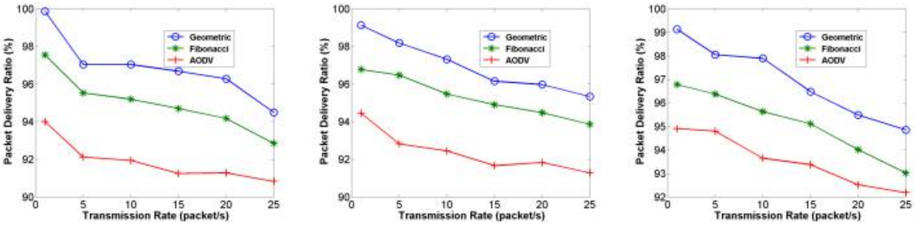
Table 1: Simulation Environment Parameters

Parameter	Value
Simulated protocols	GMRP ,FMRP and AODV
Simulation time	150 s
Simulation area	600 m* 600 m
Number of nodes	30
Node placement	Random
Bandwidth	2Mbps
Mobility model	Random waypoint
Minimum speed	0 m/s
Maximum speed	10 m/s
Pause time	0, 50, 100
Traffic type	CBR
Data packet size	512 bytes
Radio propagation model	Two-ray
Transmission range	250 m

We study the performance of the three routing protocols under variating the following control parameters, (a)packet transmission rate, (b)number of nodes, (c)network area, and the (d)node pause time. The traffic load is varied as 1, 5, 10, 15, 20, 25 packets per second. All data packets have a fixed size that is equal to 512 bytes. Number of nodes in the network is varied by 20, 25, 30, 35, 40 node. Network area is varied as (500 x 500), (750 x 750), (1000x 1000), (1250 x 1250), and (1500 x 1500). The pause time determines the mobility speed of the nodes. The nodes moves to a random location and stayed there for the pause time before it moves to another random location. We experiment with pause times of 0, 50 and 100 seconds. All results reported with 95% confidence interval. Table 1 summarizes the simulation parameters.

6. Simulation Results

Figure 6 plots the impact of packet rate on the packet delivery ratio when using Geometric based Multipath Routing Protocol (GMRP), Fibonacci based Multipath Routing Protocol (FMRP), and AODV . The reseult are shown for three pause times:0, 50 and 100 seconds. As can been seen in the figure, PDR is decreasing continuously when transmission rate is increasing. That is because when the number of packet sent by each nodes increases, this may cause congestion in the network which leads to increasing the packet dropping in the network. Moreover, it can be seen clearly that GMRP outperforms the AODV protocol, because it utilities multipath rather than a single path to deliver the packets to the destination. This means that the congestion along any single path is reduced which reduces the packet

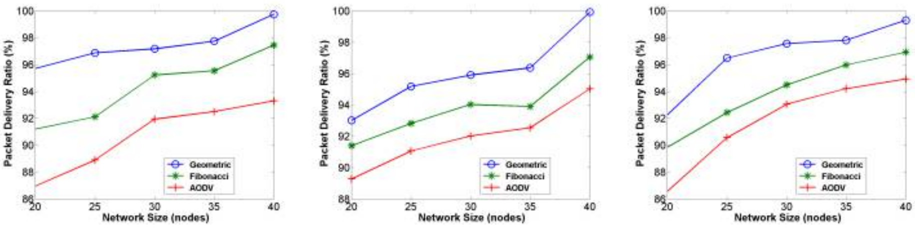


(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 6: Delivery ratio vs. transmission rate of GMRP, FMRP and AODV

dropping in that path. Besides that, if a path becomes broken, GMRP uses one of the other available paths directly without any delay. This leads to more PDR in any given time interval. Furthermore, It can be seen from the figure that the value of PDR in case of GMRP is greater than the value of PDR in case of FMRP. That is because, as explained in Figure 4, GMRP utilizes the shorter paths ao all the available paths more.

The impact of changing the number of nodes in the network, with three pause times, on PDR is shown in Figure 7. The results are shown for GMRP, FMRP and AODV. From the figure, it is obvious that GMRP outperforms the other two

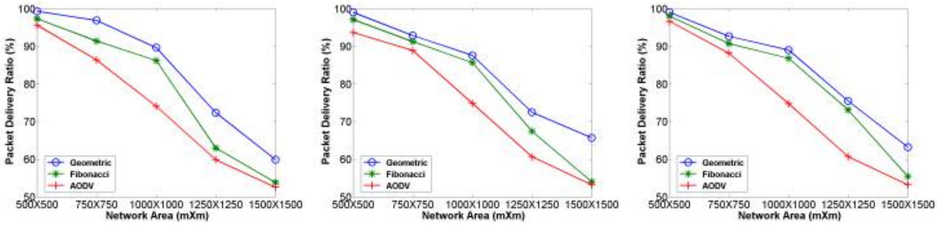


(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 7: Impact of network size on the packet dilervey ratio

protocols by achieving the highest PDR. We can notice that the PDR increases when the network size increases. This trend happens because as the network size increases, the routing protocols may find various short paths between different senders and receivers in the network which reduces the congestion over each single path which, in turn, reduces packet loss.

Finally, we studied the impact of network area on PDR. The result are shown in Figure 8. Results are shown for the three protocls under study with 0, 50, and 100 seconds pause times. The results in the figure show that PDR is decreasing when the network area is increase. This is because of, with sparse network, the number

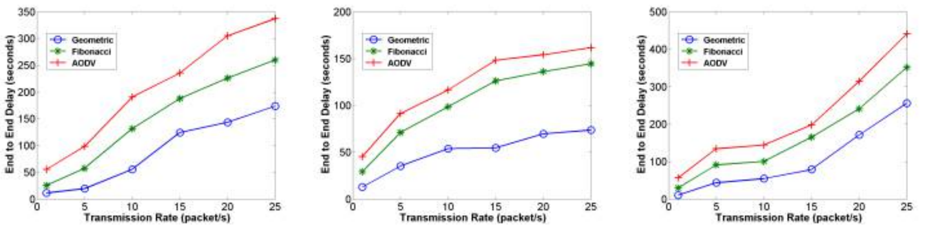


(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 8: Delivery ratio vs. Area (in meter) of GMRP, FMRP and AODV

of neighbor nodes decrease due to lack of overall connectivity. Also, this makes the routs cover longer distances which degrades the connectivity of the nodes along the path which leads to more errors in the packets.

Figure 9 displays the average end-to-end delay for GMRP, FMRP, and AODV. In

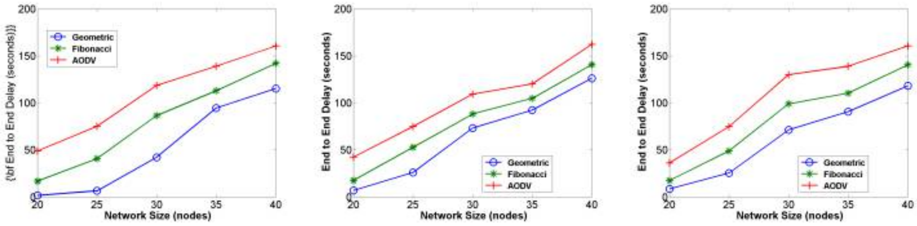


(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 9: Endtoend delay vs. transmission rate of GMRP, FMRP and AODV

the figure, and for the three pause times, endtoend delay increase when transmission rate is increased. The reason for that is when the transmission rate is increased, it may cause congestion in the network. Congestion, usually leads to more packet loss which increases packet retransmission. This may lead to have more dead nodes. As a result, the number of broken links increases. A broken link may need to reinitiate a path discovery process to find a path, instead of broken one, which increases the average endtoend delay in the network. Also we notice that the GMRP outperforms the AODV protocol because it utilizes multipath rather than a single path. It also outperform FMRP because as mentioned before it sens more packets on the shorter paths.

The Impact of network size and the pause time on the average endtoend delay is plotted in Figure 10. We notice that the endtoend delay is increasing when the network size is increased. That is because, when the number of nodes is increased, the probability to have longer paths increases as well. Packet delivery over these longer

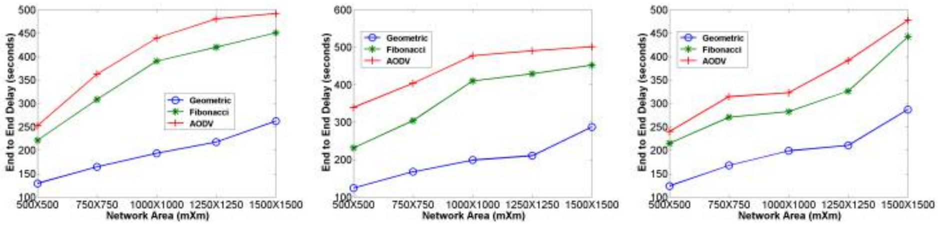


(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 10: End to end delay vs. number of nodes of GMRP, FMRP and AODV

routs results in longer average endtoend delay. The figure also show that GMRP achieves the best end-to-end delay result among all routing protocols understudy.

Finally, we studied the impact of the network area and the pause time on the average endtoend delay. The results are shown in Figure 11. In the figure, the



(a) Pause 0 (b) Pause 50 (c) Pause 100

Fig. 11: Endtoend delay vs. Area (in meter) of GMRP, FMRP and AODV with 0 second pause time

endtoend delay is increasing when the network area is increasing. This is because of sparseness of the network which leads to increasing the time needed for path discovery process, packet propagation time, and packet retransmissions. Among all protocols, GMRP achieves the shortest endtoend delay, because it re-initiates the route discovery process only when all paths are broken and it send more packets on the shorter paths of the available paths.

7. Conclusions and Future Work

In this paper, we proposed a new multipath routing protocol that uses the Geometric Sequence to distribute the sent packet over the available paths. We call the proposed protocol the Geometric Sequence Based Multipath Routing Protocol (GMRP). We evaluated the performance of the proposed protocol using GlomoSim simulator. In our simulation, we compared GMRP performance against the Fibonacci Sequence Based Multipath Routing Protocol (FMRP), that was recently proposed, and the popular single path Ad hoc On-Demand Distance Vector (AODV) routing protocol. In the experiments, we varied the network size in number of nodes and area, the node pause time, and the transmission rate. We also study the performance of the algorithm using the packet delay ration and the average end-to-end delay. The results indicated that GMRP outperforms both FMRP and AODV protocols under all studied scenarios. This is because the distribution process of the data packet over multiple paths, the proposed algorithm send more packets on the shorter paths. Future work includes studying the lifetime and the power consumption of the nodes in the network when using different routing protocols and studying the involving of other metrics to find the alternative paths such as node mobility and the available power at the nodes.

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