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Discovery of Multiple Mobile Gateways in Wireless Mesh Networks

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Abstract: In this paper we propose an efficient discovery mechanism to select the best mobile gateway in wireless mesh networks (WMN's). Our proposed scheme is based on mobile gateway learning mechanism, in which mobile gateways allow routers to discover them efficiently with minimal packet loss and packet delay. Simulation results have shown enhanced performance and throughput with minimal packet loss and packet delay as compared to previous schemes.

Key words: Mobile gateways · Periodic broadcast · Mobile gateway discovery

INTRODUCTION

Recently, wireless mesh networks (WMNs) have received incredible research attention in business, engineering, industry and academia. WMN's consist of mesh clients, mesh routers and internet gateways. Mesh routers have minimum mobility and form the backbone of WMNs [1]. In the not too distant past, the concept of mobile gateways has been introduced for WMN's [2]. Existing WMN protocols usually employ single [3,4] and multiple fixed internet gateways [5]. The protocols used for mobile ad hoc networks cannot be used directly in WMN's because both the networks are different in terms of physical topology, mobility and architecture; the peculiarity of a WMN being it self organizing and self healing character [2]. In order to connect to the internet, the client nodes send request to the mesh routers which, in turn, are responsible for forwarding the clients' requests to the gateways. However, almost all the routing protocols, used by the ad hoc networks, don't have the capability of discovering a mobile gateway and giving access to the internet [6,7]. Therefore, there should be a prescribed way for a router to discover mobile gateways in order to fulfill the clients' requests.

In this paper we propose an efficient discovery mechanism to select the best mobile gateway in wireless mesh networks (WMN's). The existing discovery schemes used for WMNs and wireless adhoc networks require the periodic broadcasts of gateway advertisement message which may result in huge traffic congestion, ultimately leading to packet loss and packet delay [8,9]. The proposed scheme tries to minimize these periodic broadcasts by the learning mechanism of the mobile gateways. Instead of redundant periodic broadcast, our scheme tries to learn the structure of network and thereafter use the learned dataset to broadcasts advertisement message at specified times, when required. The proposed scheme employ the received signal strength indication (RSSI) in order to enable mobile gateways to register or un-register the routers at precise time resulting in minimal packet loss and packet delay.

Background: The existing protocols for mobile gateways' discovery can be classified as proactive, reactive and hybrid. In proactive approaches [10,11], periodic gateway advertisement messages are broadcasted by mobile gateways, so that all the routers in the mesh can build up their routes to gateway. Proactive methods are comparatively good in connectivity but their performance is hindered by the overhead of periodic broadcasts. The reactive methods [12-14] are initiated when a client sends a request to a router and the router needs to connect to some mobile gateway. The router broadcasts gateway solicitation messages in order to register with the gateway. Packet delays and overloading are the main issues with this approach. The hybrid method [15,16], encapsulates the advantages of both reactive and proactive methods. Gateway advertisement message are only broadcasted by the gateway to the routers which they are in its range while the rest of the routers work reactively.

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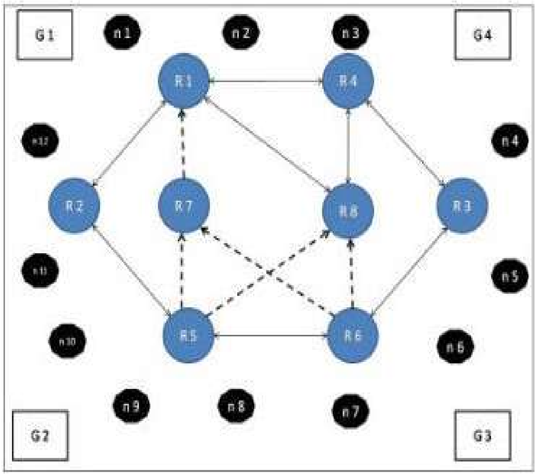

Fig. 1: Example of a periodic broadcast

The broadcast period is usually kept fixed in each of the above mentioned techniques. The standard time for broadcast period is considered to be 10 seconds [17]. While the concept of fixed broadcasting time may be justifiable in case of static gateways, for mobile gateways it may lead to performance degradation. With mobile gateway, the factors tied to mobility, especially speed, must have to be accounted for in deciding the periodic broadcast time. When the speed of mobile gateway is slow, there would be no new undiscovered routes and most of the mobile gateway advertisement messages would go useless. Not only this, but the registered routers will also receive repeated gateway advertisement messages, eventually leading to network congestion. On the other hand, if the gateway mobility is high, some routers may not receive gateway advertisement messages, resulting in inefficiency. To illustrate the peculiarity of networks involving mobile gateways, consider the scenario given in Fig. 1. Suppose the gateway G1 broadcasts gateway advertisement message every 10 seconds, the speed of the gateway is 0.5 m/s and the coverage area of gateway is 100 meters. This means that G1 will broadcast 20 gateway advertisement messages in its coverage area. The nearest routers R1 and R2 will receive 20 messages in 200 seconds. This will create huge message traffic, hence creating network congestion. Therefore, the broadcast period for a mobile gateway must be dependent on the speed of gateway, its signal strength and distance between mobile gateway and mesh routers.

To the best of our knowledge, there are few works in the literature that address the problem of mobile gateway discovery. One of such rare protocol is Multi Path Routing (MPR) [15], but in that protocol authors only focused on load balancing and no concrete technique was proposed for mobile gateway discovery. For discovery of mobile gateways, weighted cumulative expected transmission time (WCETT) routing metric [18] has been used. WCETT is the metric introduced by multi radio link quality source routing (MR-LQSR) [18]; a reactive routing protocol. The weight of the link is assigned by multi-radio LQSR and this weight is used by each node to find the best path for a particular destination. WCETT is an extended version of expected transmission time ETT in which intra-flow interference is additionally considered. The metric is basically the sum of channel diversity and end to end delay. This mechanism bounds WCETT to choose paths from congested area as well. WCETT neither guarantees shortest paths nor does it avoid inter- and intra-flow interference [19]. However, in this scheme [2], there is a tradeoff between throughput and delay because high quality channels are only considered. In [20], load balancing is achieved by using weighted cumulative expected transmission time with load balancing metric (WCETT- LB). While formulating WCETT-LB, the authors ignored to handle the delay of data packets which is much higher especially when the network is dense. Not only this, the reactive nature of the scheme may also suffer from congestion due to reactive nature of the scheme. Last but not the least, frequent path establishment requests in the network may also create congestion and cause delays.

Proposed Scheme: The proposed methodology, to be hereinafter called discovery with learning and RSSI (DLR), is a proactive routing scheme. The limitation of proactive schemes is periodic broadcasts of gateway advertisement messages. To address this limitation, the proposed scheme minimizes periodic broadcast traffic by a mechanism of mobile gateways that learns the structure of network and then, by using learned dataset, it broadcasts advertisement message at specific time intervals. Our scheme also takes into account RSSI on the basis of which the mobile gateways make the decision of registering or de-registering of routers. The dynamic registering/de-registering of routers and controlled broadcast of advertisement messages, not only reduces packet loss but also reduces packet delay. RSSI is used for the backup of the proposed scheme. The scheme consists of the following phases.

Learning Phase: During the learning phase, the gateway periodically broadcasts advertisement messages and store acknowledgments sent by different routers, in response. The mobile gateway also keeps track of its speed with the help of accelerometer [21] - a device used for measuring speed of a moving object. At the end of the learning phase, the gateway analyzes the following data:

- Speed of mobile gateways
- RSSI values
- Number of routers in vicinity
- Timestamp of new router discovery
- Timestamp of each acknowledgment from router.
- Timestamp of the last received acknowledgment by a registered router.

After analyzing the above mentioned data, the gateway computes average time for gateway advertisement message broadcast according to the following equation.

$$T_b = \frac{P_t * C_s}{P_s} \quad (1)$$

where T_b is the gateway advertisement time, P_t is the received acknowledgement time of previous message, C_s is the current speed of the mobile gateway and P_s is the speed of mobile gateway of previous round. The same equation is also used for de-registering any particular router. The only difference is in the P_t (previous time). Here we use the previous time (the last acknowledgment received time) by the gateway for any particular router in the learning phase.

In this way, all mobile gateways complete their rounds in their respective vicinities saving all the information needed. The gateway also records the total time spent to complete one round of the vicinity. This will tell the mobile gateway its starting point so that the movement of the mobile gateway is automatically synchronized with the locations of the routers.

Registration and De-registration: Once the learning phase complete and all the data saved, the mobile gateway will start its working. Now, the mobile gateways register the routers in their range. The registered routers will flood the network with registration messages so that un-registered routers can update their routing tables accordingly.

During gateway mobility if gateway senses considerable weakening of signals (indicated by RSSI) from a registered router, it would take a decision of de-registeration on the basis of following equations:

Table 1: Simulation Parameters

Simulation Tool	OMNET++ v4. (INET framework)
Field Dimensions	1000 * 1000
Number of Mobile Gateways	1-20
Number of Static Mesh Routers	6-120
Number of Mobile Mesh Routers	6
Packet Size	512 Bytes
Speed of Mobile Gateway	2-10 meter/seconds

C - D > Threshold (Register the router) (2)

C - D < Threshold (Do not register/De-register) (3)

- Where C is the current value of the RSSI and D is the difference between current and previous value of RSSI, i.e.

D= P-C.

Using equations (1), (2) and (3), the mobile gateway will also calculate the non-reception time of the registered router to de-register them. After receiving the de-registration message from the mobile gateway, the router will flood this de-registration message to the network so that routing table of all other routers should be updated. Our scheme is adaptable in the sense that, at any time, when gateway speed varies, it finds a new broadcast time by using the equations (1), (2) and (3). Our simulation results showed that the network is not over burdened due to the periodic broadcast created by the mobile gateway as in previous schemes. Hence minimizing the network congestion which will result is minimal packet loss and packet delay. In the next rounds, the mobile gateways will re-adjust its gateway advertisement time with the help of Equation (1).

Simulation Results: The simulations have been carried out in OMNET++ v4.0 based framework called INET. The range of parameters employed in the said simulations are listed in

Table 1 along with there values. We have compared the results of our proposed method with those of the Multi Path Routing scheme (MPR) given in [15]. The results are summarized below

Traffic Load: Figure 2 shows the effect of load on packet delay. Both our protocol and the MPR protocols were simulated using 5 and 8 mobile gateways with a packet load of 5-20 packets at each mobile gateway. The resultant packet delay was calculated in seconds. As shown in the figure, the delay increases with increase in packet load for both the protocols i.e. MPR and DLR. As DLR uses

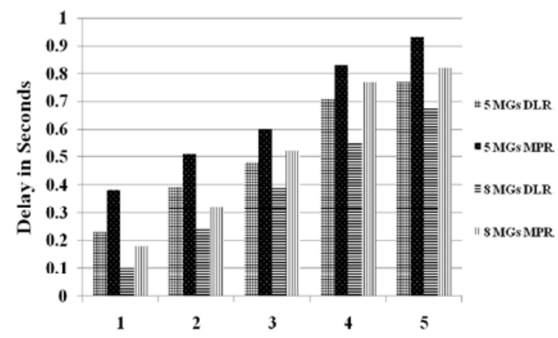

Fig. 2: Effects of Load on Packet Delay

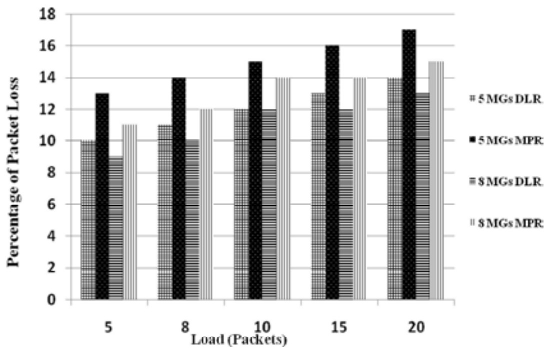

Fig. 3: Effect of Load on Packet Loss

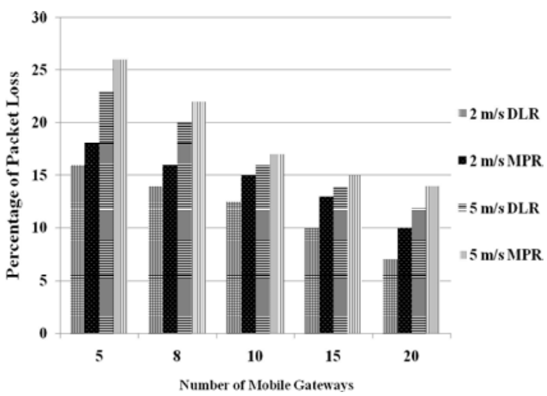

Fig. 4: Effects of Speed on Packet Loss

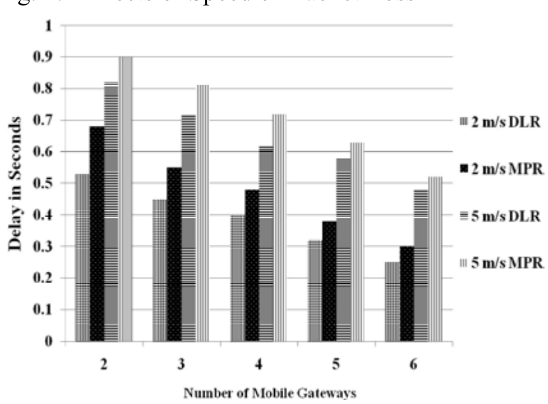

Fig. 5: Effects of Mobile Routers on Packet Delay

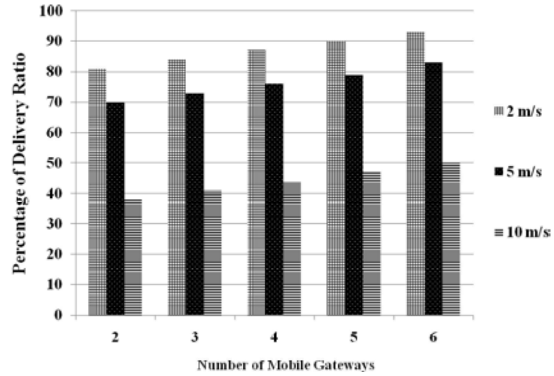

Fig. 6: Delivery Ratios with Respect to Speed

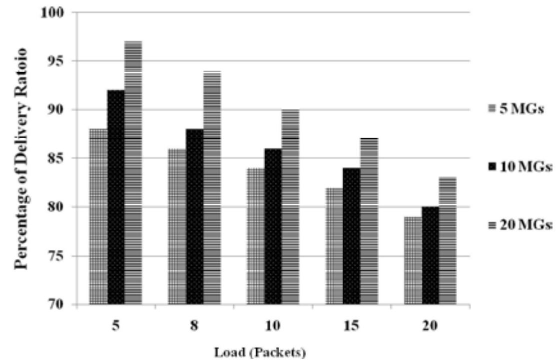

Fig. 7: Effects of Load on Delivery Ratio

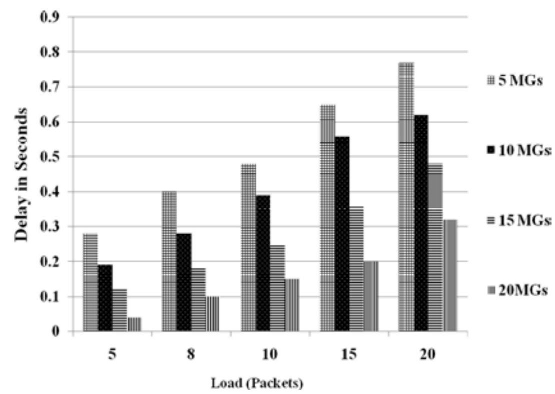

Fig. 8: Effects of Load on Packet Delay up to 20 Mobile Gateways

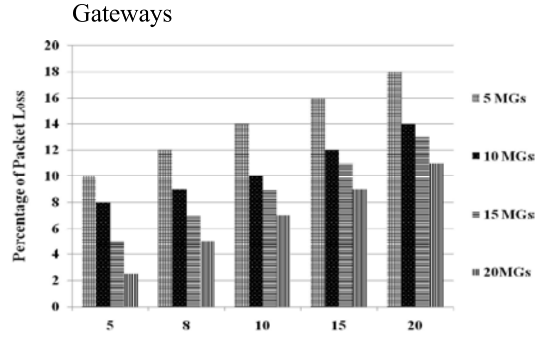

Fig. 9: Effects of Load on Packet Loss upto 20 Mobile Gateways

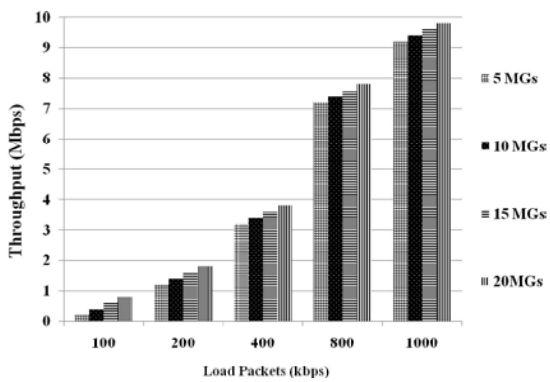

Fig. 10: Effects of Load on Throughput

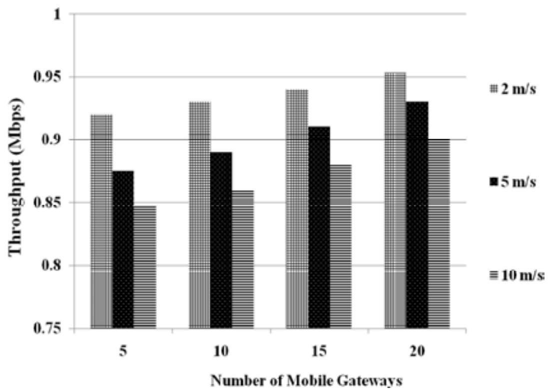

Fig. 11: Effects of Speed on Throughput

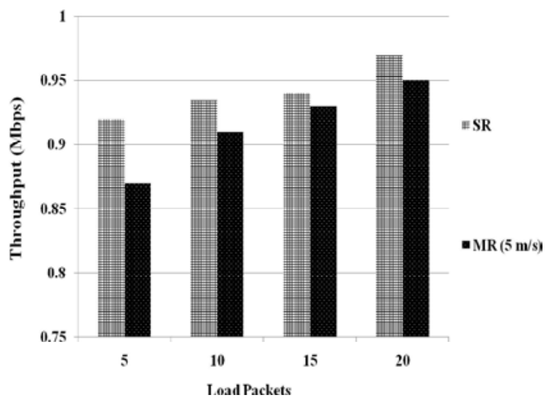

Fig. 12: Effects of Mobile Routers on Packet Delay

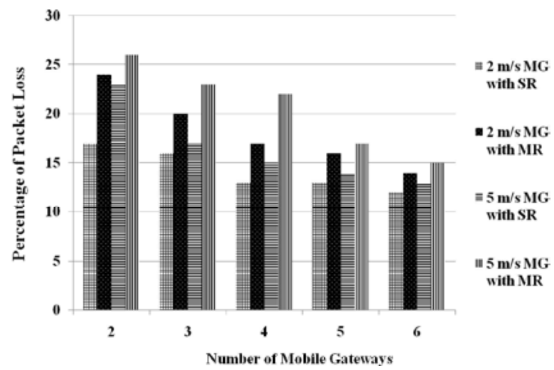

Fig. 13: Effects of Mobile Routers on Packet Loss

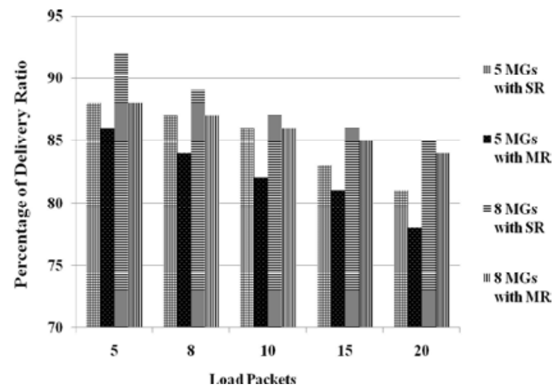

Fig. 14: Effects of Mobile Routers on Delivery Ratio

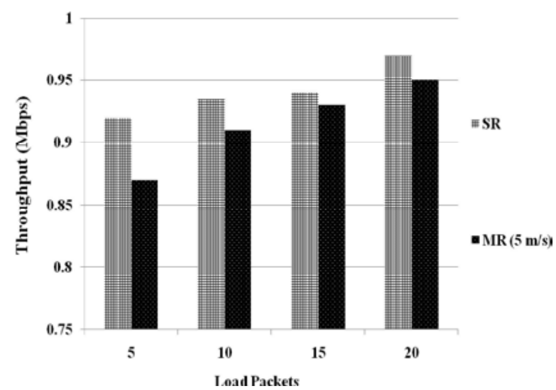

Fig. 15: Effects of Mobile Routers on Throughput

efficient gateway discovery scheme and have minimized periodic broadcasts, it outperforms MPR. (MPR was discussed below Fig 1.

Figure 3 shows effect of load on packet delay. As shown in the figure, packet loss increases with increase in packet load for both the protocols i.e. MPR and DLR. This is because, an increase in load increases packet delay and the high delay due to gateway mobility increases the packet loss. As DLR uses efficient gateway discovery scheme and incur less packet delay compared to MPR, packet loss of DLR is also less than MPR.

Gateway: Figure 4 shows the effect of gateway speeds and number of gateways on packet loss. Both DLR and MPR protocols were simulated using 2-6 mobile gateways with two different speeds of 2m/s and 5m/s.

The graph shows that packet loss decreases by increasing the number of gateways. This is because the more the gateways, higher is the connectivity which results in better load balancing. It can be concluded from simulation results that packet loss can be reduced by increasing the number of mobile gateways. Since we have already shown the DLR superior to the MPR in terms of packet loss, hence even if the number of mobile gateways is increased the results will be the same as before.

Figure 5 shows effect of increasing the number of gateways on packet delay in seconds. Simulation result shows that packet delay decreases as the number of mobile gateways increase. This is because increased number of mobile gateways provides more connectivity and efficient load balancing for each gateway. Hence, packet delay can be reduced by increasing number of gateways.

The delivery ratio was analyzed with respect to different gateway speeds involving 2 to 6 mobile gateways with gateway speeds of to 2 m/s, 5 m/s and 10 m/s. The results are drawn in Figure 6 which shows that by increasing number of gateways, packet loss is reduced which means increased packet delivery ratio. While on the other hand if speed of gateways is increased, this will decrease increase packet loss which means decreased packet delivery ratio. Hence it is concluded that if gateways are highly mobile, we have to use increased number of gateways to minimize packet loss and increase packet delivery ratio.

Figure 7 shows effect of different loads on delivery ratio for the scenario outlined for Figure 6.

Studying delay as a function of load for various numbers of gateways in a network involving static routers gave the results shown in Figure 8. The rest of the simulation parameters were the same as used for the previous simulations. As expected, packet delay escalated with the increasing load on gateways. Same was the case with the packet loss in this scenario, as shown in Figure 9.

Figure 10 shows effect of different number of gateways and loads on throughput for the above scenario. A load of 100 to 1000 kbps assigned to each mobile gateway and throughput was calculated in mbps. Simulation result showed that throughput increases when number of mobile gateways is increased.

Figure 11 shows effect of the mobile gateways on throughput. For this, simulation is done using 5, 10, 15 and 20 mobile gateways with speed of 2 m/s 5 m/s and 10 m/s. Simulation results show that throughput is decreased by increasing the speed of mobile gateways. Hence it is concluded that if gateways are highly mobile and we want to achieve high throughput, we would have to use increased number of gateways.

Mobile Routers: DLR protocol was then simulated with a router mobility amounting to 2m/s speed. The rest of the parameters were as use before, i.e.2-6 mobile gateways with speeds of 2m/s and 5m/s. Inside the mesh backbone, we considered 6 mobile routers (MR's) are made mobile. Simulation results have shown that packet delay decreases as mobile gateways are increased but when MR's are involved instead of static routers (SR's), the packet delay escalates, as can be observed in Figure 12. The reason being the lower stability of networks involving MR's, compared to those with SR's. In general, packet delay increases as the router mobility increases, e.g. MR's with 5m/s speeds cause more delay than those with 2m/s speeds. With the delay in packets and mobility of routers, packet loss also increases. This can be seen in Figure 13 which represents the effect of packet loss involving the same set up. It is obvious that packet loss decreases as mobile gateways are increased but with the involvement of MR's the packet loss is increased further because the network becomes less stable.

Figure 14 shows effect of mobile routers and different loads on delivery ratio. As discussed earlier, by using mobile routers packet loss is increased compared to static routers.

Figure 15 shows effect of mobile routers on throughput. During simulation, 5, 10, 15 and 20 mobile gateways were used. Inside the mesh backbone, 6 routers were set mobile to check ultimate effect of routers mobility on throughput. As shown by earlier graphs, mobile routers have increased packet delay and packet loss and this result was not different from excepted. Simulation results show that throughput increases with increase in number of mobile gateways. But, throughput of network which uses mobile routers, is low compared to throughput of network which uses static routers. There are many reasons behind this which are already discussed in previous graphs. Hence, it is concluded that throughput of network using mobile routers is less compared to network which uses static routers. (Sir I think there would be repetition of content which is not good)

We also studied packet delay as a function of load for various numbers of mobile gateways (MG's) with the rest of parameters being the same as taken above, with 6 routers being made mobile. Simulation results showed that packet delay increases by increasing load on gateways

CONCLUSION

The simulation results showed high throughput and delivery ratio with minimal packet loss and packet delay. Even when the network is dense, the results are better as compared to the previous schemes. The results of the simulation proved that proposed scheme is efficient enough to handle dense situations. It was observed that the use of mobile routers inside the mesh backbone degrades performance. Mobile routers cannot be used in mesh backbone because path breakage may occur, resulting in network partitioning. Mobile routers inside the mesh backbone results in packet loss and packet delay which affects the throughput of the network.

As a future goal, an efficient scheme is needed to handling the mobile routers inside the mesh backbone with minimal packet loss and packet delay. Moreover, there is a need to efficiently handle situations where the coverage area of the mobile gateway is huge and its speed is high to avoid packet loss and packet delay. We employed homogeneous routers but in addition to those, issues linked with the use of heterogeneous routers need also be addressed.

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