Performance Analysis of On-Demand Routing Protocols in Wireless Mesh Networks

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Wireless Mesh Networks (WMNs) have recently gained a lot of popularity due to their rapid deployment and instant communication capabilities. WMNs are dynamically self-organizing, self-configuring and self-healing with the nodes in the network automatically establishing an adiej hoc network and preserving the mesh connectivity. Designing a routing protocol for WMNs requires several aspects to consider, such as wireless networks, fixed applications, mobile applications, scalability, better performance metrics, efficient routing within infrastructure, load balancing, throughput enhancement, interference, robustness etc. To support communication, various routing protocols are designed for various networks (e.g. ad hoc, sensor, wired etc.). However, all these protocols are not suitable for WMNs, because of the architectural differences among the networks. In this paper, a detailed simulation based performance study and analysis is performed on the reactive routing protocols to verify the suitability of these protocols over such kind of networks. Ad Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Dynamic MANET On-demand (DYMO) routing protocol are considered as the representative of reactive routing protocols. The performance differentials are investigated using varying traffic load and number of source. Based on the simulation results, how the performance of each protocol can be improved is also recommended.
Keywords: *Wireless Mesh Networks (WMNs), IEEE 802.11s, AODV, DSR, DYMO.*

1 Introduction

Now-a-days Internet connections are limited for wire line infrastructure deploying a DSL, T1 or cable-modem based connection. Nevertheless, wire line infrastructures are more expensive and time-consuming to set up than a wireless one. Besides, the providers of the developing countries are not willing to install the necessary equipment such as optical fiber, copper-wire and other infrastructures for broadband services with little profit at the rural areas. Therefore, Wireless Networks have emerged as a promising solution to overcome this crisis. It provides high data rate over wide areas for a large number of users, and better services rather than wired network. Moreover, it provides several facilities which include low cost equipment, ensure interoperability, and reduce investment risk for operators.

The Wireless mesh networks (WMNs) are dynamically self-organization, self-configured and self-healing, with the nodes in the network automatically setting up an ad hoc network and preserving the mesh connectivity [1]. Wireless mesh is functionally similar to the standard IEEE 802.11 infrastructure network with respect to its Basic Service Set (BSS) and Extended Service Set (ESS). The novelty is that, if the source and the destination station are not in the same BSS domain, the source Access Points (AP) does not forward the packet to all the APs in the ESS but the packet is sent along an APs or station path to reach the destination station. The stations are relay competence and the mesh APs are called Mesh Points (MPs). The Wireless Distribution System (WDS) uses an extension of the IEEE 802.11 MAC/PHY to provide a protocol for auto configuring paths between MPs in a multi-hop topology, supporting broadcast, multicast and unicast traffic.

WMNs currently use three categories of protocols such as Proactive, Reactive and hybrid. Proactive routing protocols maintain routes to all destinations, regardless of whether these routes are needed or not. To preserve correct route information, a node must periodically send control messages. Therefore, proactive routing protocols may waste bandwidth since control messages are sent out unnecessarily when there is no data traffic. Reactive routing protocols only set up a route between a source and its destination when required. Hybrid routing protocols combine both reactive and proactive routing to increase the overall scalability in the networks. In this paper we only focused on reactive routing protocols due to its advantages compare to others. The rest of the paper is organized as follows. Related works are discussed in section 2. Descriptions of reactive routing protocols are given in Section 3. Section 4 describes simulation environment. Results are discussed and analyzed in section 5. Finally, conclusion is drawn in section 6.

2 Related Works

In recent years, several wireless routing protocols are designed to provide communication in wireless environment, such as AODV, OLSR, DSDV, ZRP, LAR, LANMAR, STAR, DYMO etc. Performance comparison among some set of routing protocols are already performed by the researchers such as among PAODV, AODV, CBRP, DSR, and DSDV [2], among DSDV, DSR, AODV, and TORA [3], among SPF, EXBF, DSDV, TORA, DSR, and AODV [4], among DSR and AODV [5], among STAR, AODV and DSR [6], among AMRoute, ODMRP, AMRIS and CAMP [7], among DSR, CBT and AODV [8], among DSDV, OLSR and AODV [9] and many more. These performance comparisons are carried out on ad hoc networks. No comparison is performed on reactive protocols over wireless mesh network. Therefore, evaluating the performance of reactive routing protocols in wireless mesh network environment is still an active research area and in this paper we study and compare the performance of AODV, DSR, and DYMO routing protocols.

3 Reactive Routing Protocols

A. Ad hoc On-demand Distance Vector (AODV)

Ad hoc On-demand distance vector (AODV) [10] is another variant of classic distance vector routing algorithm, based on DSDV [11] and DSR [12]. It shares DSR's on-demand characteristics, discovers routes on an as needed basis via a similar route discovery process. However, AODV adopts traditional routing tables; one entry per destination which is in contrast to DSR that preserves multiple route cache entries for each destination. The early design of AODV is undertaken after the experience with DSDV routing algorithm. Like DSDV, AODV provides loop free routes in case of link breakage but unlike DSDV, it doesn't need global periodic routing advertisement. AODV uses a broadcast route discovery algorithm and then the unicast route reply massage. The following sections explain these mechanisms in more details.

1) *Route Discovery:*

When a node wants to send a packet to some destination and does not have a valid route in its routing table for that destination, initiates a route discovery. Source node broadcasts a route request (RREQ) packet to its neighbors, which then forwards the request to their neighbors and so on. Fig. 1 indicates the broadcast of RREQ across the network. To control network-wide broadcasts of RREQ packets, the source node use an expanding ring search technique. In this technique, source node starts searching the destination using some initial time to live (TTL) value. If no reply is received within the discovery period, TTL value incremented by an increment value. This process will continue until the threshold value is reached.

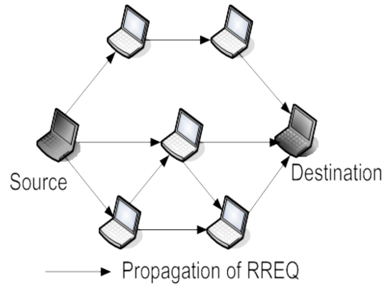


Fig. 1. Propagation of RREQ throughout the network

When an intermediate node forwards the RREQ, it records the address of the neighbor from which first packet of the broadcast is received, thereby establishing a reverse path. When the RREQ reaches a node that is either the destination node or an intermediate node with a fresh enough route to the destination, replies by unicasting the route reply (RREP) towards the source node. As the RREP is routed back along the reverse path, intermediate nodes along this path set up forward path entries to the destination in its route table and when the RREP reaches the source node, a route from source to the destination establish.

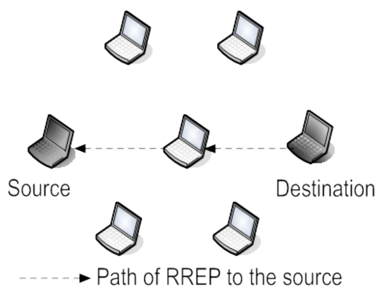


Fig. 2. Reply of RREP towards the network

Figure 2 indicates the path of the RREP from the destination node to the source node.

2) *Route Maintenance:*

A route established between source and destination pair is maintained as long as needed by the source.

If the source node moves during an active session, it can reinitiate route discovery to find out a new route to destination. However, if the destination or some intermediate node moves, the node upstream of the break remove the routing entry and send route error (RERR) message to the affected active upstream neighbors. These nodes in turn propagate the RERR to their precursor nodes, and so on until the source node is reached. The affected source node may then choose to either stop sending data or reinitiate route discovery for that destination by sending out a new RREQ message.

B. Dynamic Source Routing (DSR)

The Dynamic Source Routing (DSR) [12] is one of the purest examples of an on-demand routing protocol that is based on the idea of source routing. It is designed especially for use in multihop ad hoc networks for mobile nodes. It allows the network to be completely self-organizing and self-configuring and does not need any existing network infrastructure or administration. DSR uses no periodic routing messages like AODV, thereby reduces network bandwidth overhead, conserves battery power and avoids large routing updates. Instead DSR needs support from the MAC layer to identify link failure. DSR is composed of the two mechanisms of Route Discovery and Route Maintenance, which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the network. The following sections explain these mechanisms in more details.

1) Route Discovery:

When a mobile node has a packet to send to some destination, it first checks its route cache to determine whether it already has a route to the destination. If it has an unexpired route, it will use this route to send the packet to the destination. On the other hand, if the cache does not have such a route, it initiates route discovery by broadcasting a route request packet.

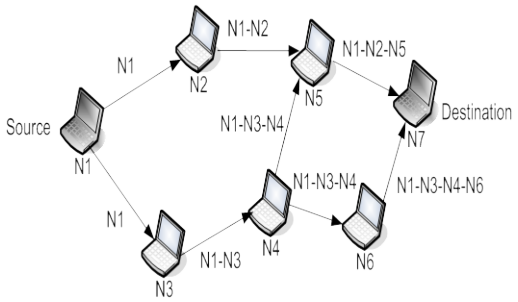


Fig. 3. Propagation of route request message across the network

Each node receiving the route request packet searches throughout its route cache for a route to the intended destination. If no route is found in the cache, it adds its own address to the route record of the packet and then forwards the packet to its neighbors. This request propagates through the network until either the destination or an intermediate node with a route to destination is reached.

Figure 3 demonstrates the formation of the route record as the route request propagates through the network.

Whenever route request reaches either to the destination itself or to an intermediate node which has a route to the destination, a route reply is unicasted back to its originator. Fig. 4 illustrates the path of the RREP from the destination node to the source node

Whenever route request reaches either to the destination itself or to an intermediate node which has a route to the destination, a route reply is unicasted back to its originator.

2) Route Maintenance:

In DSR, route is maintained by using route error packets and acknowledgments. When a packet with source route is originated or forwarded, each node sending the packet is responsible for confirming that the packet has been received by the next hop. The packet is retransmitted until the conformation of receipt is received. If the packet is transmitted by a node the maximum number of times and yet no receipt information is received, this node returns a route error message to the source of the packet. When this route error packet is received, the hop in error is removed from the host's route cache and all routes containing the hop are truncated at that point.

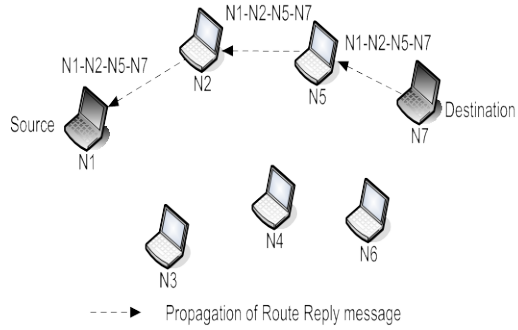


Fig. 4. Propagation of route reply message towards the source

C. The Dynamic MANET On-demand (DYMO):

The Dynamic MANET On-demand (DYMO) [13] routing protocol is a simple and fast routing protocol for multihop networks. It determines unicast routes among DYMO routers within the network in an on-demand fashion, offering improved convergence in dynamic topologies. To ensure the correctness of this protocol, Digital signatures and hash chains are used [14]. The basic operations of the DYMO protocol are route discovery and route management. The following sections explain these mechanisms in more details.

1) Route Discovery:

Route discovery is the process of creating a route to a destination when a node needs a route to it. When a source node wishes to communicate with a destination node, it initiates a Route Request (RREQ) message. The route discovery process is illustrated in Fig. 5.

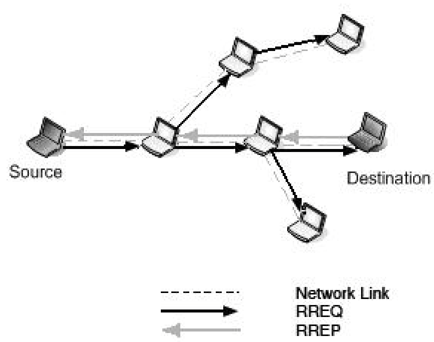


Fig. 5. The DYMO route discovery process

In the figure, source node wants to communicate with destination node. In the RREQ message, the source node includes its own address and its sequence number, which is incremented before it is added to the RREQ. It can also include prefix value and gateway information if the node is an Internet gateway capable of forwarding packets to and from the Internet. Finally, a hop count for the originator is added with the value 1. Then information about the destination node is added. The most important part is the address of the destination node. If the originating node knows a sequence number and hop count for the target, these values are also included. Upon sending the RREQ, the originating node will await the reception of an RREP message from the target. If no RREP is received within RREQ waiting time the node may again try to discover a route by issuing another RREQ. When the RREQ reaches the destination node, an RREP message is then created as a response to the RREQ, containing information about destination node, i.e., address, sequence number, prefix, and gateway information, and the RREP message is sent back along the reverse path using unicast. Similar to the RREQ dissemination, every node forwarding the RREP adds its own address to the RREP and installs routes to destination node.

2) Route Maintenance:

Route maintenance is the process of responding to changes in topology that happens after a route has initially been created. To maintain paths, nodes continuously monitor the active links and update the Valid Timeout field of entries in its routing table when receiving and sending data packets. If a node receives a data packet for a destination it does not have a valid route for, it must respond with a Route Error (RERR) message. When creating the RERR message, the node makes a list containing the address and sequence number of the unreachable node. In addition, the node adds all entries in the routing table that is dependent on the unreachable destination as next hop entry. The purpose is to notify about additional routes that are no longer available. The node sends the list in the RERR packet. The RERR message is broadcasted. The dissemination process is illustrated in Fig. 6. A link breakage node (LBN) receives a data packet for destination node. When it finds a link is broken, it will wait up to node timed out period after that the entry has become invalid. LBN generates an RERR message, which is propagated backwards towards source node.

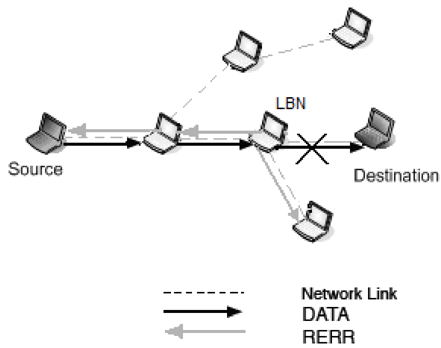
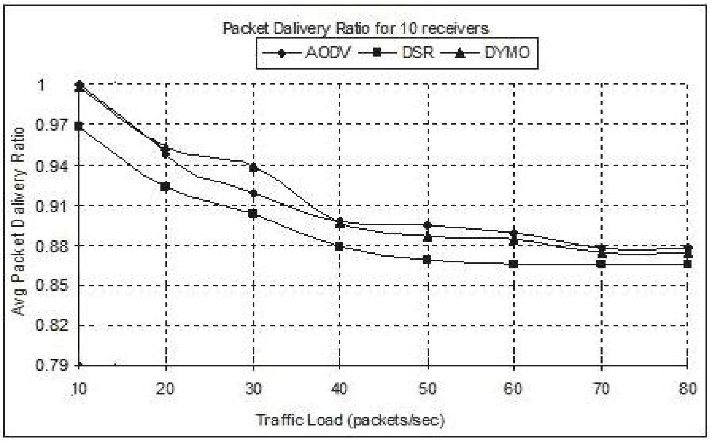


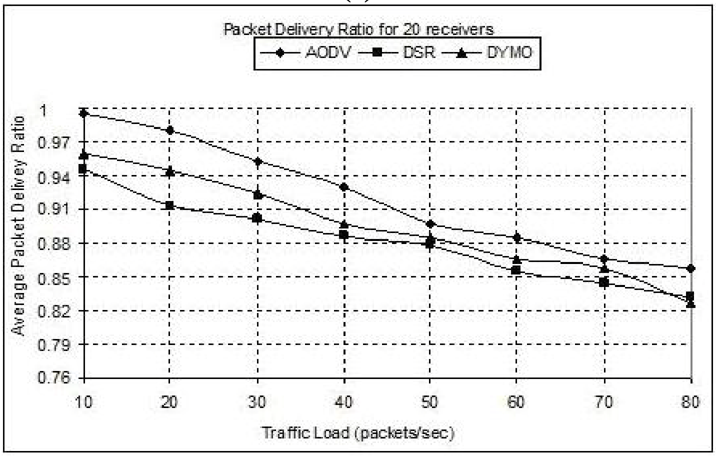
Fig. 6. Generation and dissemination of RERR messages

4 Simulation Environment

The overall goal of this simulation study is to analyze the performance of different existing wireless routing protocols in WMNs environment. The simulations have been performed using QualNet version 4.5 [15], a software that provides scalable simulations of Wireless Networks and a commercial version of GloMoSim [16]. In our simulation, we consider a network of 100 nodes (one source and one destination) that are placed randomly within a 1000m X 1000m area and operating over 500 seconds. Multiple runs with different seed numbers are conducted for each scenario and collected data is averaged over those runs.



(a)



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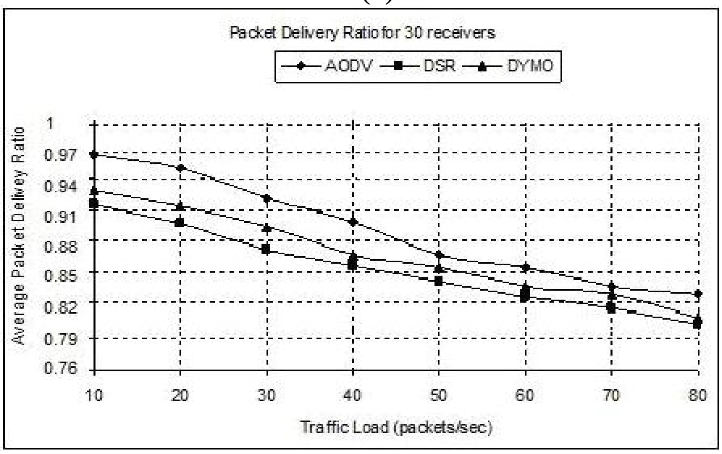
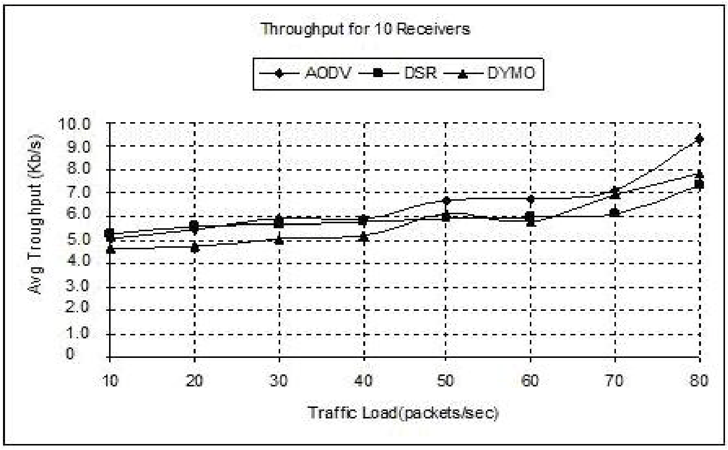
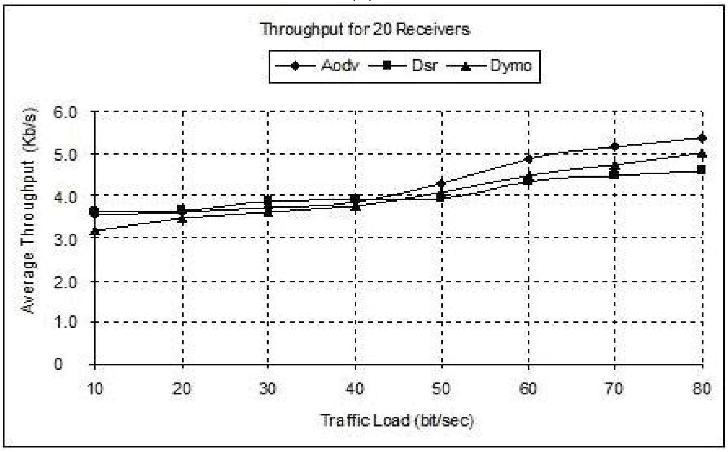


(c)

Fig. 7. Packet Delivery Ratio, (a) for 10 receivers, (b) for 20 receivers, (c) for 30 receivers.



(a)



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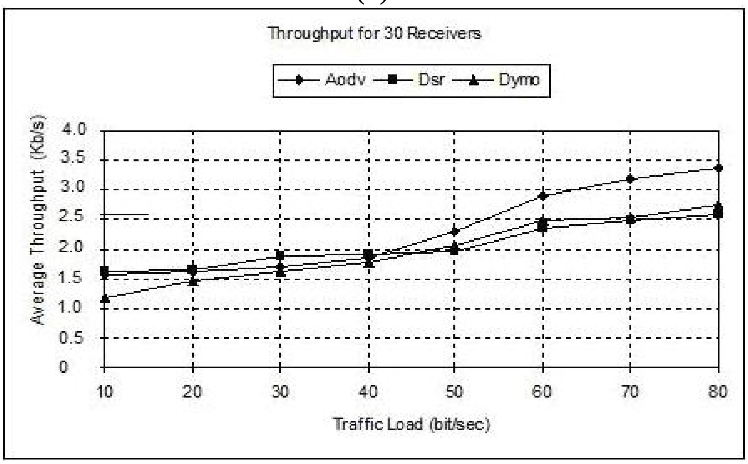

(c)

Fig. 8. Throughput, (a) for 10 receivers, (b) for 20 receivers, (c) for 30 receivers.

A two-ray propagation path loss model is used in our experiments with lognormal shadowing model. The transmission power of the routers is set constant at 20 dBm and the transmission range of the routers is 250 meters. The data transmission rate is 2Mbits/s. At the physical layer 802.11b and at MAC layer MAC 802.11 is used. The traffic source is implemented using Constant Bit Rate (CBR), sending at a rate of 1 packets/s. The packet size without header is 512 bytes. The length of the queue at every node is 50 Kbytes where all the packets are scheduled on a first-in-first-out (FIFO) basis.

To evaluate the performance of routing protocols, both qualitative and quantitative metrics are needed. Most of the routing protocols ensure the qualitative metrics. Therefore, we use four different quantitative metrics to compare the performance. They are

- Packet Delivery Ratio: The fraction of packets sent by the application that are received by the receivers [18].

- Jitter: Jitter is the variation in the time between packets arriving, caused by network congestion, timing drift, or route changes.
- Average End-to-end delay: End-to-end delay indicates how long it took for a packet to travel from the source to the application layer of the destination. [19].
- Throughput: The throughput is defined as the total amount of data a receiver R receives from the sender divided by the times it takes for R to get the last packet [20].

5 Result and Discussion

The performance differentials in this simulation are investigated using varying traffic load and number of sources. Traffic load is varied from 10 packets/sec to 80 packets/sec where it is increased by 10 packets/sec. On the other hand, number of sources is increased from 10 sources to 30 sources. The results gained from simulations are illustrated in Fig 7 to 10.

In Fig 7(a), 7(b) and 7(c), packet delivery ratio obtained for AODV, DSR and DYMO for various sources, 10, 20 and 30 are shown respectively. At the beginning when traffic load was 10 packets/sec, all three protocols display high packet delivery ratio. However, packet delivery ratio decline with increasing traffic load. It can easily be observed that AODV and DYMO perform much better than DSR. DSR does not have a mechanism to expire stale routes in the cache, or to prefer "fresher" routes when face with multiple routes [5]. Consequently, if stale routes are used, it causes two problems, such as, 1) consumption of extra network bandwidth interface queue slots even though the packet is finally dropped or delayed and 2) possible pollution of caches in other nodes. On the other hand, AODV and DYMO have better approach than DSR. They choose fresher route if they have multiple routes. Therefore, DSR performs worse than AODV and DYMO.

Fig 8(a), 8(b) and 8(c) show the throughput comparison of AODV, DSR, and DYMO at various numbers of sources. The general observation from the simulation is that for application- oriented metric throughput, DSR outperforms AODV in less "stressful" situations (lower traffic load). AODV, however, outperforms DSR in more stressful situation. The poor throughput performance of DSR is caused by its aggressive use of caching and stale route problem.

DYMO is predominantly a successor of AODV. Therefore, the architecture is similar like AODV. DYMO is made for MANET, however, we do our simulation for WMNs. In the overall simulation, we have got that AODV outperform than DYMO

Conclusions

A simulation based performance comparison of three different reactive protocols (AODV, DSR, and DYMO) is described in this paper. Simulation has been conducted over wireless mesh environment. From the result of our studies and analysis, it can be concluded that, on an average AODV perform better than DYMO and DSR. However, the overall performance of the three protocols in WMNs is not quite good. The major reason behind the performance degradation is because all these protocols are designed mainly for ad-hoc network. Though some features of ad hoc networks are similar to WMNs, they have lots of features those are different from each other. For instance, to develop an ad-hoc routing protocol, features need to be considered are mobility, limited power consumption, adaptability, flexibility, security, scalability etc.

On the other hand, to design routing protocol for wireless mesh network, requires to consider fixed application, mobile application, scalability, better performance metrics, efficient routing within infrastructure, robustness etc. Existing ad-hoc routing protocols have already considered some of the features of WMNs but not all the features, due to their different architecture. To improve these protocols performance, multiple matrices, multi radio, multi path, cross-layer technique etc can be considered. Consequently, existing protocols need to be enhanced or re-invented for WMNs.

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