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A New Routing Protocol for WMNs

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***Abstract* --** Opportunistic routing is an emerging research area in Wireless Mesh Networks (WMNs), which exploits the broadcast nature of wireless networks to find the optimal routing solution that maximizes throughput and minimizes packet loss. Opportunistic routing protocols mainly suffer from computational overheads, as most of the protocols try to find the best next forwarding node. In this paper we address the key issue of computational overhead by designing new routing technique without using pre-selected list of potential forwarders. We propose a novel opportunistic routing technique for WMNs. We compare it with well-known protocols, such as AODV, OLSR, and ROMER based on throughput, delivery ratio, and average end to end delay. Simulation results show that proposed protocol, gives average throughput increase up to 32%, and increase in delivery ratio (from 10% to 20%). We also analyze the performance of proposed protocol and ROMER based on various parameters, such as duplicate transmissions and network collisions, by analysis depicts that proposed protocol reduces duplicate transmissions up to 70% and network collisions up to 30%

Keywords: *AODV, OLSR, ROMER, WMNs*

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I. Introduction

Wireless technologies made the communications more flexible and reduced the wired networks overheads as well as cost [1,2], but at the same time, researchers are facing many challenges in their implementation. Wireless applications are increasing promptly and Wireless Mesh Networks (WMNs) provide an effective platform for them [1,3]. WMNs provide self-organized and self-configured network infrastructure [4]. In WMNs, mesh connectivity is performed dynamically [1]. WMNs offer many benefits, such as: easy deployment, lower cost, and reliable service coverage [1]. Currently, routing protocols used in WMNs have been adopted from Adhoc Networks. Most of these protocols are proactive and perform routing by establishing the path, prior to send or receive data [5]. Unlike Adhoc and wireless sensor networks, WMNs have no energy constraints [6,7]. However wireless link quality changes due to different reasons [8], such as: The link may become congested and bandwidth may reduce due to interference or distance between nodes. Wireless medium is unreliable and signal quality varies. Therefore, selected route may suffer from packet loss and delay during the transmission of data [8]. To overcome aforementioned problems, opportunistic routing is being explored, which exploits the broadcast behavior of WMNs. Opportunistic routing eliminates the overheads posed by proactive protocols. The key advantage of opportunistic routing in Node-disjoint multi-path routing method [9], is that it provides the opportunity to send the packets to far-off nodes [10]. Another advantage of opportunistic routing is that it combines many lossy physical links to form a strong virtual link [10]. Whenever a node is ready to send a packet, it simply broadcast the packet without calculating the predefined path. The packet is sent to its destination by deciding the path on the fly [11]. Dynamic or on the fly path selection provides an opportunity to select the optimal path, whenever a better opportunity (in terms of link quality, congestion, link load, etc.) is available during the transmission in opportunistic routing. Opportunistic routing protocols are an active area of research, and deliver better performance in WMNs in terms of reduced number of retransmissions, increased throughput, and better delivery ratio as compared to the Adhoc routing protocols [11]. However, the issue of duplicate transmissions in opportunistic routing needs to be addressed to reduce the broadcast overhead without losing the benefits of enhanced throughput and delivery ratio. As the wireless spectrum is limited and the number of devices is growing, saving the bandwidth by avoiding unnecessary transmissions are indispensable. In this paper, our motivation is to design a low overhead and high performance opportunistic routing protocol. We proposed a new opportunistic routing protocol that provides an effective opportunistic routing solution by adopting a region based forwarding scheme that reduces duplicate transmissions and provides higher throughput and delivery ratio as compared to other conventional and opportunistic routing protocols. Rest of paper is organized as follows. In Section 2 we provide the literature review of conventional and opportunistic wireless routing protocols, in Section 3 we explained our proposed protocol, in Section 4 we discussed simulation setup and results. In Section 5 we present our conclusion.

II. Related work

Since various types of wireless networks such as Wireless Adhoc Networks, Wireless sensor networks, MANETs and Wireless mesh networks have different network architectures and applications. Therefore, they have different requirements for routing protocols. WMNs are considered similar to Adhoc networks and MANETs, therefore, routing protocols for these networks are also adopted in WMNs [11] . However, these protocols do not fit well in WMNs. Traditional routing protocols cause a lot of retransmissions and frequent execution of route discovery process [12]. Therefore, new routing protocols are required for WMNs that addresses the drawbacks of traditional routing protocols. Routing protocols in wireless networks are divided in two basic categories, (a) Adhoc routing protocols, and (b) opportunistic routing protocols. They are described in detail below.

A. Adhoc routing protocols

In this section, we discuss state of the art Adhoc wireless routing protocols. These protocols are further divided in two categories [3]. Namely: proactive routing protocols and reactive routing protocols. Proactive routing protocols are those that already have the information about the network topology. Nodes maintain and update the paths for different destinations in their routing table [3]. These protocols are similar to the table driven routing protocols which are being used in wired networks with some variations [13]. Destination sequence distant vector (DSDV) [14] and Optimized Link State Routing (OLSR) [15] belong to this category. Reactive routing protocols are those which do not maintain the topology information with them [13]. When a node wants to transmit it initiates a route discovery process, i.e., routes is calculated on demand [13]. Route remains accessible until: (a) the destination is available or (b) route is no longer required [13]. Dynamic Source Routing (DSR) [16] and Adhoc on demand distant vector (AODV) [17] are the reactive routing protocols. AODV performs well in terms of throughput, delay and delivery ratio. However, DSR is suitable for low bandwidth; energy constrained, and moderate mobility networks.

B. Opportunistic routing protocols

Opportunistic routing is an emerging research area in WMNs [10, 11]. Opportunistic routing reduces the number of retransmissions; however, probability of duplicate transmission increases. Hence, retransmission avoidance comes with the drawback of duplicate transmissions by the relay nodes and decreased throughput. To avoid this drawback of opportunistic routing nodes are required to communicate with each other and mitigate the effect of duplicate forwarding. For this purpose acknowledgments between nodes can be used to avoid the duplication. However, overhead caused by excessive acknowledgments can decrease the benefits of opportunistic routing significantly. Research in [18] explains the potential gain of opportunistic routing: opportunistic gain is significantly higher when modeled in line of sight configuration and it decreases when the communication is not in the line of sight. Unlike legacy routing protocols which maintains a dedicated path towards a destination, opportunistic routing protocols do not select a path before transmission and the selection of next forwarder is delayed till the receipt of packet at next hop. Opportunistic routing works on the principle of broadcast to exploit the broadcast nature of wireless networks. Hence, each node which receives the packet becomes the potential forwarder. To control the flooding, opportunistic routing protocols, select best forwarder among all potential forwarders in order to transmit successfully towards desired destination [10, 11]. Opportunistic routing protocols are divided into two categories, namely, (a) Single rate opportunistic routing protocols, (b) Multi-rate opportunistic routing protocols.

B.1. Single rate opportunistic routing protocols

Single rate opportunistic routing protocols transmit at fixed rate continuously i.e., transmission rate does not vary at any link in the path. Extremely Opportunistic Routing (ExOR) protocol [19] is a pioneer opportunistic protocol which gives the concept of opportunistic routing in WMNs. ExOR uses the links cost computed by Expected Transmission Count (ETX) routing metric to make the routing decisions. Each node calculates its cost towards destination and shares it with its neighbors. When a node has to transmit data towards the destination, it simply broadcast that data to its neighbors. Source node calculates priorities of next potential forwarders and makes a priority list. For coordination purpose, forwarder priority list is sent in each data packet. Each relay node calculates its own priority list for next potential forwarders and broadcast to its neighbors. Priority is calculated using the ETX value, the lesser the value of ETX, the higher will be the priority to the node. To avoid the duplication, ExOR uses batch of packets. Each batch contains data packets, sender’s guess of prioritized list of nodes, and information of that batch called the ‘batch map’. Which is provided to all the other nodes that receive the packet? High priority node rebroadcast the packet. After receiving the acknowledgment of received packets, if some packets remain unacknowledged, the second highest priority node in batch map retransmits the unacknowledged packet. The process continues until all the packets are acknowledged. MAC and routing are combined to avoid duplicate transmissions from multiple nodes. Simple Opportunistic Adaptive Routing (SOAR) protocol [20] is an opportunistic proactive link state routing protocol for WMNs. It also uses ETX routing metric to calculate the link quality and selects the next hops for forwarding list. When a source broadcasts the packet, the nodes in the forwarding list store the packet and other nodes discard it. All the nodes that receive the packet set a forwarding timer based on their estimation to reach the destination. The nodes, which are nearer to the destination set smaller timer, while the nodes that are far from destination set higher timers. When a timer of a node expires, it starts transmission. On hearing this transmission, other nodes remove those packets from their queue to avoid duplicate transmission. Each node maintains a routing table that contains a destination, default path, and forward list for each packet/node. Default path is the shortest path to the destination calculated using ETX routing metric. SOAR trims down the actual path to the nodes that are nearer to the default path. By using this technique duplicate transmission on multiple diverse paths is avoided because all forwarding nodes are near the default path and hence probability of listening each other transmission becomes high. However, sending of forwarders list is still an overhead. Resilient Opportunistic Mesh Routing (ROMER) [21] is an opportunistic routing protocol. Unlike ExOR and SOAR, it does not calculate the priority list of next potential forwarders, instead a credit is used which is set initially by the sender and decreases as packet propagates hop by hop. When an intermediate node receives a packet, it calculates the remaining credit and compares with the credit required to reach the destination. If the value of remaining credit is less than the threshold, it simply discards it; otherwise, broadcasts the packet to its next available hops. The sender sends a packet to multiple receivers, hoping one of them will be in good link state. In this way, ROMER avoids retransmissions due to lossy links and provides resilience. Duplicate packets may be received when credit value is set high. Credit distribution can be done using different techniques. ROMER [21] gives more credit to initial nodes to quickly expand the mesh network. Later on mesh reduces, as packet propagates further downstream. Each node calculates its minimum cost towards gateway, by using simple flooding method or through other available protocols for this purpose. Maximum Opportunistic Routing Protocol (MaxOPP) [22] is a novel opportunistic routing scheme. Unlike SOAR and ExOR, MaxOPP avoids pre-selected nominated forwarders as well as pre assigned time for forwarding. MaxOPP uses ETX routing metric to calculate the cost of each link. When source node sends a packet, intermediate nodes receive those packets and calculate the remaining cost of path. Nodes calculate the opportunistic gain by subtracting the cost of current node towards destination from the remaining cost. If the opportunistic gain is greater than 0 then node is a potential forwarder, otherwise it discards the packet. If the opportunistic gain is positive, then before taking the final decision of forwarding, node calculate the opportunistic gain ratio by dividing its own opportunistic gain with its previous hop's opportunistic gain. The ratio is compared with the threshold value cP0. If opportunistic gain ratio is greater than c then the node forwards the packet, otherwise it discards the packet. MaxOpp uses the least cost mechanism to determine the cost of the nodes. To avoid the duplication, sequence number is used. However, duplicates are discarded at receiver after the transmission takes place.

B.2. Multi-rate opportunistic routing protocols

In multi rate opportunistic routing, transmission rate varies according to the conditions of network at each hop. Multi-rate Geographic Opportunistic Routing (MGOR) [23] works upon two heuristics, (a) Expected Advancement Rate (EAR) [24], and (b) Expected Advancement Time (EMT) [23]. Another multi rate WMN routing protocol is the shortest multi rate any path forwarding (SMAF) [24] which calculates the opportunistic multi rate path based on Dijkstra algorithms. Another technique for routing is network coding in which packets are encoded combine and at receiver decoded back. Using this technique, multiple packets are sent in a single transmission. EXOR and SOAR pre selects the list of next relay nodes at each hop and sends this information along with the packets, which cause overhead. This pre selection of relay nodes also reduces the advantage of broadcast nature of wireless networks However, ROMER and MaxOPP do not calculate the preselected list of relay nodes, routing decision is taken by next hops according to the parameters discussed. In this case problem of duplicate packet transmission occurs. We proposed a new opportunistic routing scheme, which not only avoid the pre selection of next hop relay nodes but also reduces the number of duplicate packet transmissions. Table 1 shows comparative summary of few state of the art protocols, in terms of some basic properties.

C. Proposed protocol

In our proposed scheme, gateway node is the destination node. The destination node send a packet with area number equal to zero and nodes which received this packet set their area number one unit more than area number field in the packet. These nodes copy their area number to the packet and rebroadcast it. This procedure continues until all nodes in the network receive the packet once. Note that nodes process and rebroadcast this packet just once. Area number of nodes is their distance to the gateway or destination node in hop count.

We supposed that the gateway node do not move and is stationary, but the other nodes can move. If a node moves its distance to the destination node changes and there is a need to update the node information from the network topology. To handle this situation nodes broadcast a hello packet periodically and notify their area number to their one hop neighbors. If a node move and find itself in a situation that have not received a hello packet with one unit more than its area number the its find the lowest area number in the received hello packets at least triple times add one to that area number and set it as its area number.

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Source node broadcast its data packet with its area number. All of its neighbor nodes received this packet and compare their area number with the source node area number. If their area number than the source node area number then they have permission to rebroadcast this packet. But to reduce the duplicate packets they wait for a random interval and when this interval expires they broadcast the packet. When a node rebroadcast a packet other nodes in its neighborhood add ACK_TIME to their wait interval. If they received acknowledgment from a node with lower area number for that packet drops the packet.

D. Simulation results

We evaluate proposed protocol using NS2.34 and compare with Adhoc and opportunistic routing protocols. We compared our proposed protocol with OLSR [15] a proactive routing protocol, AODV [17] a reactive routing protocol and with ROMER [21] a single rate opportunistic routing protocol. To evaluate the performance of proposed protocol, we compared the performance based on parameters; throughput, delivery ratio and average end to end delay. Another comparison carried out between proposed protocol and ROMER (a similar nature opportunistic routing protocol), is based on two parameters (a) duplicates, and (b) collisions. We carried out our simulation for two different transmission rates i.e. 250 kbps and 500 kbps for 5 different nodes set (10, 30, 50, 75 and 100 nodes). We carried out 3 simulations of each protocol for every number of nodes and then took the average of the result to get our final results. Table 2 shows the simulation parameters used.

Table 2

Type	Parameters	Value
Network	Field dimensions	1000 m _ 1000 m
	Network deployment	Grid
	Number of nodes	10, 30, 50, 75, 100
	Transmission range	250 m
	Interference range	550 m
	Antenna type	Omni antenna
	Propagation model	Two ray ground
Application	Agent	UDP
	Application	CBR
	Data packet size	1000 bytes
	Data rate	11 Mb
	Transmission rate	250 kbps, 520 kbps
	Number of channels used	1
	Carrier frequency	2.472e9
	MAC protocol type	Mac/802.11
	Simulation time	2000s

A. Throughput

Throughput is the average data successfully received at destination in given time slot. We calculate the throughput by using the Eq. 1.

$$Throughput = \frac{PacketRecievd \times PacketSize \ \times UDP\ Header}{Run\ time} \qquad 1$$

In Fig. 1 numbers of nodes are at x-axis and corresponding throughput at y-axis to for the compared protocols (OLSR, AODV, ROMER, and PROPOSED PROTOCOL). Fig. 1 shows the throughput increase by proposed routing over AODV, OLSR and ROMER for different topologies.

It can be observed that for proposed protocol throughput is constantly higher for increasing number of nodes than other Adhoc and opportunistic routing protocols. Proposed protocol achieves this throughput gain due to its region based forwarding by limiting the number of forwarders to avoid broadcast storm. Moreover, proposed protocol uses delayed transmission and implicit acknowledgments which results in avoiding the unnecessary transmissions to reduce the congestion and collisions. Fig. 2 shows the graph for throughput when transmission rate is increased to 500kbps. It can be observed that as number of nodes is increasing, proposed protocol performs comparatively better in terms of throughput among other protocols. However, throughput for all protocols decreases as node density increases. Increasing the transmission rates, results in range decreases which causes the decrease in throughput.

Fig 1

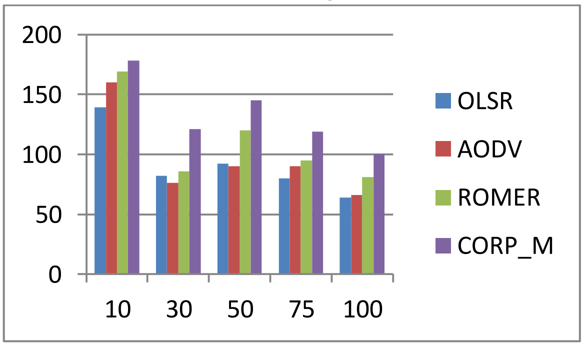
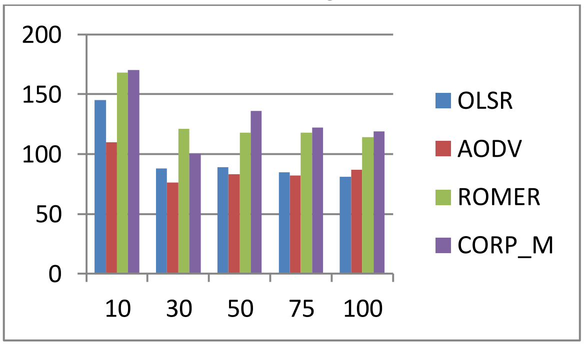


Fig 2



B. Delivery ratio

Delivery ratio is calculated by taking the percentage of total packets received against total packets sent.

$$DeliveryRatio = \frac{Total\ Received\ Packet}{Total\ sent\ Packet} \times 100 \qquad 2$$

In Fig. 3 numbers of nodes are at x-axis and corresponding delivery ratio at y-axis to for the compared protocols (OLSR, AODV, ROMER, and PROPOSED PROTOCOL). Fig. 3 shows the simulation results of delivery ratio for transmission rate 250 kbps. We observe that proposed protocol has performed well for all the topologies among all compared protocols. Proposed protocol has the highest delivery ratio. In high link error rate opportunistic routing gives better reliability to achieve higher delivery ratio as compared to the conventional routing protocols. Increasing the number of nodes reduces the delivery ratio of AODV and OLSR which was initially high relatively, possibly due to selfish nodes, which drop the packets to save their resources. Fig. 4 shows the simulation results of delivery ratio for transmission rate 500 kbps. We observe that delivery ratio of the all protocols drop as compared to the graph for transmission rate 250 kbps. This is due to the reason that with high transmission rates loss probability increases and transmission range decreases. In opportunistic routing, delivery ratio decreases when node density decreases. However, we have fixed node density and tested our protocol with higher transmission rate.

Fig 3

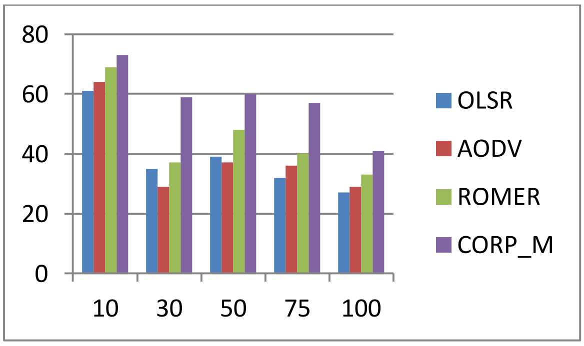
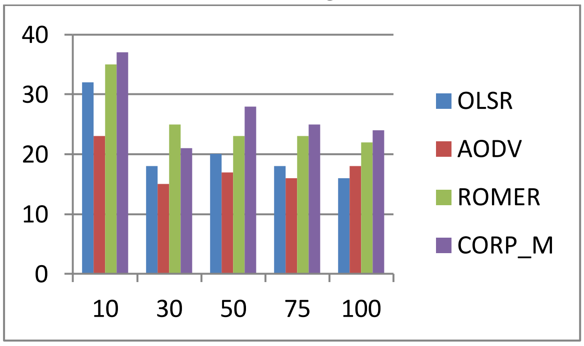


Fig 4



C. Average end-to-end delay

Average end-to-end delay is the time a packet consume after transmission from source node to reach destination node. To calculate the average end-to-end delay we first calculate the delay of each packet after transmission to reach the destination and then take the average. In Fig. 5 numbers of nodes are at x-axis and corresponding average end-to-end delay at y-axis to for the compared protocols (OLSR, AODV, ROMER, and PROPOSED PROTOCOL). Fig. 5 shows the simulation results for average end-to-end delay for 250 kbps. We observe that Adhoc routing protocols show the low delays while the opportunistic routing protocols have the higher values of average end-to-end delay. This is due to the reason that opportunistic routing protocols, broadcast whenever they get an opportunity, therefore, after reaching the certain level end-to-end delay increases due to collisions in Ready To Send(RTS). Another reason is, instead of immediately transmitting the packets, Opportunistic routing protocols use a delay for packet transmissions to avoid the duplications. Therefore, ROMER and proposed protocol have higher average end-to-end delays. However, both protocols give high throughput and better delivery ratio. In comparison with ROMER, proposed protocol gives better results for smaller topologies. However, for large topologies, it gives higher delay. This is due to the reason that proposed protocol uses a hold timer to avoid the duplicate transmission. Unacknowledged packets are retransmitted after the timer expires. Consequently, unacknowledged packets cause the average end-to-end delay to be high for proposed protocol. However, this is a tradeoff to avoid the duplicate transmission. Fig. 6 shows the simulation results for average end-to-end delay for transmission rate 500kbps. We observe that proposed protocol performs better for higher transmission rate in larger topologies. Increasing the transmission range reduces the delay by involving the less number of hops to forward the packets; it is the core of opportunistic routing that allows the transmission to cover the maximum possible distance without predefining the next hop node. Results show that all protocols give higher delay when number of nodes are increasing. OLSR shows the highest average delay and proposed protocol shows the stability when number of nodes is increasing.

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Fig 5

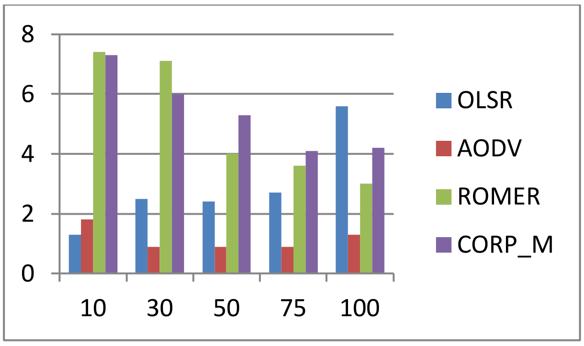
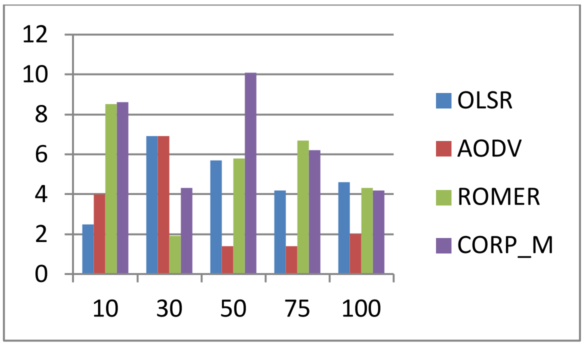


Fig 6



D. Duplicate packet transmissions

Duplicate packet transmissions are those packets which are already received by a node and again received by same node from another node. We compare only Opportunistic routing protocols on the basis of duplicate packets received. In Fig. 7 numbers of nodes are at x-axis and corresponding duplicate packet transmissions at y-axis to for the compared protocols (OLSR, AODV, ROMER, PROPOSED PROTOCOL). Fig. 7 shows the simulation results for Duplicate packets when transmission rate is 250 kbps. Graph shows that proposed protocol transmitted very low duplicate packets as compared to the ROMER. This is due to the reason that proposed protocol uses hold timer, which allows the packet the maximum probability to reach the next region. Only those packets are retransmitted by relay nodes, which are not acknowledged implicitly. Fig. 8 shows the simulation results for duplicate transmission at transmission rate 500 kbps. Graph indicates that proposed protocol efficiently reduces duplicate transmissions as compared to the ROMER. There is also a visible increase in duplicate transmissions, when we compare results of 500 kbps with 250 kbps, especially in case of 100 nodes when topologies become congested and increased transmission rate reduces the transmission range. When transmission rate is increased and network becomes more congested, bandwidth may decrease along shortest paths, which allow proposed protocol to follow other longer but optimal paths. Therefore, this inclusion of more nodes in path results in higher number of duplicate transmissions. However, in comparatives results of proposed protocol and ROMER. Proposed protocol outperforms ROMER in terms of reducing the number of duplicate transmissions, resulting in higher throughput and better delivery ratio.

Fig 7

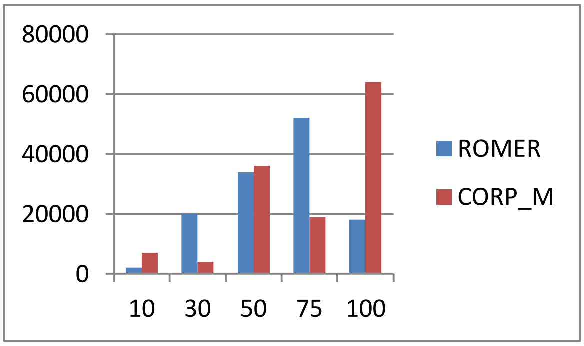
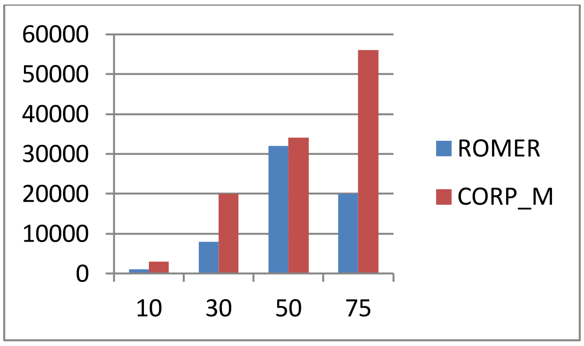


Fig 8



E. Collisions

We calculate the collisions at each node for proposed protocol and ROMER. In Fig. 9 number of nodes is at x-axis and corresponding collisions are occurred at y-axis to for the compared protocols (OLSR, AODV, ROMER and PROPOSED PROTOCOL). Fig. 9 shows the results of collisions are occurred for transmission rate 250 kbps graph indicates that as the number of nodes increases, the difference in collisions between proposed protocol and ROMER also increases. Proposed protocol technique reduces the unnecessary transmissions which results in reduced number of collisions. Fig. 10 shows the results of collisions for transmission rate 500 kbps. At x-axis we placed the number of nodes and at y-axis we placed collisions. Graph shows that there is a slight increase when transmission rate is doubled until 75 nodes. But at 100 nodes collisions are reduced. In [25] study shows that with increase in interference, collision probability does not increase linearly. Due to proposed protocol dynamic path selection process for each packet optimal paths are used with higher bandwidth which may not be the shortest path. Figs. 6 and 8 shows that for 100 nodes average end to end delay is reduced and duplicate transmissions are increased. Figs. 1 and 3 also show that throughput and delivery ratio of proposed protocol is higher than all other protocols for 100 nodes. This means that proposed protocol technique efficiently works when collisions are less, topology is larger, and transmission rate is higher. Proposed protocol ensures the successful transmissions by increasing the duplicate transmissions when required.

Fig 9

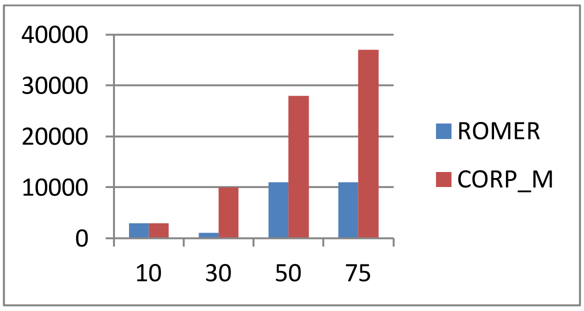
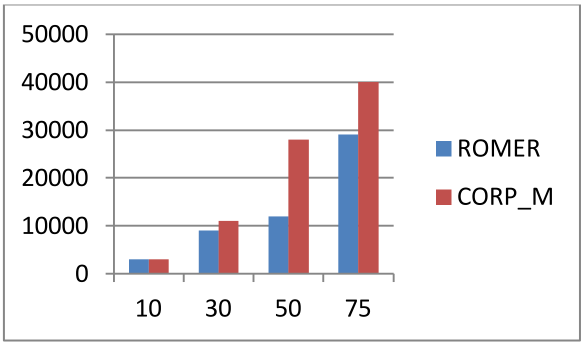


Fig 10



III. Conclusions

In this paper, we presented proposed protocol, an opportunistic routing protocol. We proposed a 'region based' next forwarder selection scheme, which simplifies the process of next forwarder selection by providing the opportunity to relay packets toward the nodes, nearer to destination with priority. Simulation results show that proposed protocol gives significant improvement as compared to the conventional and opportunistic routing protocols in terms of delivery ratio (up to 10–20%), throughput (up to 32% average increase), and optimal end-to-end delay. Another comparison with opportunistic routing protocol (ROMER) shows that proposed protocol reduces duplicate transmission up to 70%. That is a significant improvement. In future we plan to evaluate proposed protocol performance for Adhoc Networks using different mobility models.

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