Optimized Opportunistic Routing in Highly Dynamic Ad hoc Networks

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Abstract:

Opportunistic Routing is a promising paradigm that has been proposed for efficient and reliable transfer of data packets in mobile ad hoc networks. This routing strategy takes advantage of the broadcasting nature of the wireless medium to increase the number of probable forwarding devices and improves the reliability of data transfer in the network. Opportunistic Routing utilizes the reception of the same broadcasted packet at multiple devices in the network and selects one best forwarder dynamically from the set of multiple receivers. A number of opportunistic routing protocols have been proposed over these years for effective data delivery in ad hoc networks. But as the speed and mobility of devices increases in the network, performances of the existing opportunistic routing protocols degrade considerably, leading to reduced Quality of Service and poor transmission efficiency. The exceptional potential of opportunistic routing is thus underutilized. In this research we introduce Optimized Opportunistic Routing (OOR) strategy that guarantee excellent Quality of Service and high transmission efficiency to the latest applications using opportunistic routing for communication in highly dynamic ad hoc networks. Simulation results show that our method achieve significant performance improvements compared to all other existing opportunistic routing protocols in highly dynamic mobile ad hoc networks.

Keywords

Ad Hoc Networks; Highly Dynamic; Mobility; Opportunistic Routing; Performance Improvement; Transmission Inefficiency

1. Introduction

Mobile ad hoc networks (MANETs) [1-10] are a collection of wireless devices like mobile phones, laptops, PC's and iPads that can form instantaneous temporary networks without the support of any pre-existing network infrastructure or centralized control. It works as an autonomous system of mobile hosts connected by wireless communication links. The network is configured in a way that all the devices can dynamically join or leave the network at any time without disrupting communication between other devices. Every device in the network plays the dual role of a router and a host, cooperates and coordinates with each other to make routing decisions in the network. Data is transmitted in the network in a store and forward manner from the source node to the destination node via the intermediate nodes. Ease of deployment, speed of deployment and the ability to self-organize and self-adapt without the help of any underlying infrastructure has contributed to the growing popularity of MANETs in research as well as in industry. Today MANETs are used for communication and resource sharing in wide range of applications.

Numerous advancements in wireless technology have enabled mobile devices in MANETs to move freely with higher speeds in random directions. The mobility and speed of these wireless devices have become highly unpredictable and is increasing day by day. Also the number of connected devices in the network is increasing rapidly leading to highly dense and scalable ad hoc networks. These scenarios have led to the generation of highly dynamic mobile ad hoc networks (HDMANETs) in which numerous number of connected wireless devices move with higher speeds in random directions. HDMANETs offer a number of challenges to various applications due to its unique properties. The main characteristics of HDMANETs include continuous movement of wireless devices, higher speeds of wireless devices, unpredictable movement of devices in random directions, higher number of connected devices, dynamic connections, disconnections and reconnections of devices.

Routing and timely delivery of data packets have remained highly challenging task in HDMANETs because of the unpredictable movement and higher speeds of the connected devices. Traditional topology based protocols like Destination Sequenced Distance Vector (DSDV) [11], Optimized Link State Routing (OLSR) [12], Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) [13], Dynamic Source Routing (DSR) [14], Associativity-Based Routing [15], Ad hoc On Demand Distance Vector (AODV) [16] and Temporally Ordered Routing Algorithm (TORA) [17] depend on predetermined routes between source and destination devices. With highly mobile nodes it is impossible to maintain a deterministic route. Also the discovery and recovery procedures are time and energy consuming. Thus they suffer from serious performance degradation in HDMANETs and are highly ineffective. The new class of protocols known as geographic routing protocols [18-22] used location information to route the packets in a hop by hop fashion from the source device to the destination device. Greedy Perimeter Stateless

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Routing (GPSR) [18] is one of the most referenced protocol in this category. This protocol selects the device that has maximum progress to the destination (nearest to the destination) as the best forwarder to forward the data packet. When this strategy was not possible in some region in the network, GPSR used a technique of routing around the perimeter of the region. But the major problem with this category of protocols in HDMANETs was when the best forwarder device moved away from the current location and was unable to forward the data packet.

A major breakthrough in this area was provided with the discovery of opportunistic routing (OR) and opportunistic data forwarding [23]. Opportunistic routing protocols [23-33] were proposed to offer reliable data delivery and excellent Quality of Service (QoS) to applications using MANETs for communication and resource sharing. Numerous advantages offered by OR protocols have enabled researchers to use them for communication in MANETs deployed in some of the harshest environments like volcanoes, hurricane affected regions and underground mines. They are currently being used in a wide range of applications spanning from communication between rescue workers in disaster recovery operations [34-36], battlefield communications [37], industrial sites interconnection [38], emergency evacuation and recovery [39, 40] setting up communication in conferences and exhibitions to providing internet connections in rural areas [41].

Today, these applications using opportunistic routing for communication in MANETs are faced with two major challenges; the exponential rise in the number of connected devices and continually increasing mobility of these devices. As the number and mobility of the wireless devices increases at a rapid rate leading to HDMANETs, applications that uses OR protocols for communication suffers from three major problems that leads to its transmission inefficiency. Redundant data forwarding at the intermediate devices, high time overhead from frequent packet retransmissions and inefficiency in handling communication voids are the major reasons contributing to this inefficiency and low Quality of Service. Due to these problems, most modern applications that use OR protocols for communication in environments likes volcanoes, hurricane affected regions and underground mines are unable to guarantee excellent Quality of Service and high transmission efficiency to the users.

This research paper proposes Optimized Opportunistic Routing to overcome these problems and to improve the efficiency of opportunistic routing protocols in highly dynamic ad hoc networks. The paper is organized as follows. Section 2 discusses optimized opportunistic routing.

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The performances of the proposed methods are compared with the popular OR protocols using simulations in the next section. Finally, we conclude with future research directions.

2. Optimized Opportunistic Routing

A simple and novel opportunistic forwarding technique termed as Optimized Opportunistic Routing (OOR) is proposed. The method would ensure reliable and continuous data transmission between highly mobile devices in HDMANETs and also reduce the time overhead caused by packet retransmissions. The major advantage of OOR is that it is simple and can be easily implemented without major modifications to MAC protocol. Further, the overhead caused is very less compared to existing OR protocols. In OOR every wireless device is assumed to be aware of its position and the position of its immediate neighbor devices. Information about the neighbor devices is piggybacked in the transmitted data packet. The location of the destination device is retrieved by the position look up and registration service given by [13]. As soon as the position of the destination device is obtained, the source device attaches the position information to the data packet. At every forwarder device an inspection is done to check whether the destination device is in its neighbor list. If found the packet is directly delivered to the destination device. This avoids extra routing overhead in our protocol.

Working of OOR is illustrated in Figure 4.1. Two different scenarios are considered. In the first normal scenario, a wireless device S1 wants to send a message to another device 'D1' in the network. Initially device 'S1' creates a candidate list referred as Forwarder Priority List (FPL) of all neighboring devices that are in the transmission range of 'S1' based on the nearness to the destination and using Algorithm 1. The device that is nearest to the destination, device 'C' is selected as the Highest Priority Forwarder (HPF) in the list. The remaining devices, Next Forwarder Nodes (NFN) are sorted based on the Expected Distance Advancement with Delivery Probability (EDADP) metric that combines the distance progress to the destination with the probability of data delivery over each transmission link.

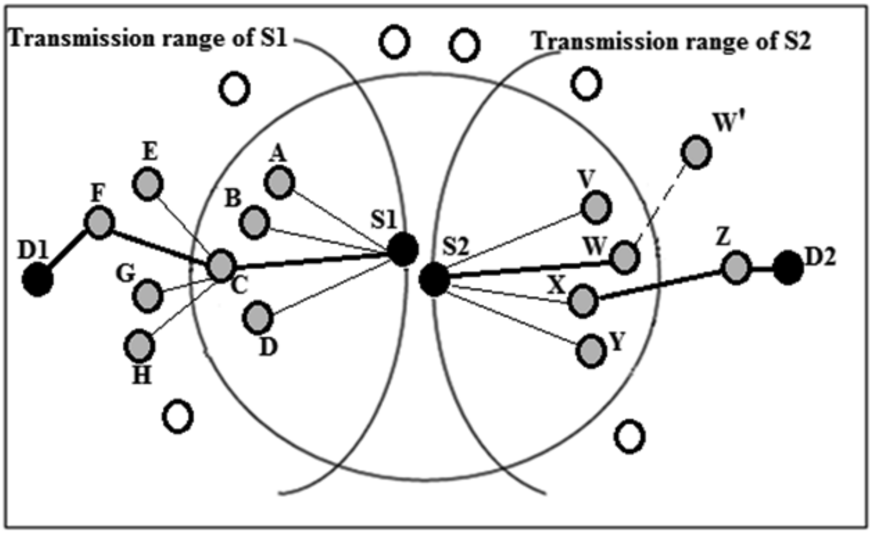

Figure 1. Working of OOR

In all scenarios the device that is nearest to the destination is selected as the Highest Priority Forwarder (HPF). This helps in maximizing the progress of the data packet towards the destination and also reduces the overhead in further computation of other metrics values. Our results show that in majority of cases the data is forwarded by the HPF. Next Forwarder Nodes (NFN) are considered in few cases only. When a data packet is received by the device marked as HPF in the FPL that is attached to the transmitted data packet, it immediately forwards the data packet to the destination. When a data packet is received by all other nodes, they would wait for particular time before retransmission. If it receives a copy of the same data packet within this time, it understands that the HPF has forwarded the data packet and it discards the data packet.

In Scenario 2 a source device 'S2' is transmitting data packets to destination device 'D2' in the network. Here the HPF device 'W' has moved away from its current location to a new location W' and is unable to forward the data packet. Once the HPF is unable to forward the data packet OOR selects the select the candidate node with maximum EDADP value to forward the data packet to the destination. This ensures minimum retransmissions because the candidate selected has excellent distance progress and very high data delivery probability in the network. So the remaining forwarders (RF) V, X and Y are sorted based on EDADP value nodes. Let us assume that node 'X' has a higher EDADP value. So if 'X' doesn't receive a copy of the same data packet within a particular time it understands that HPF has moved away is unable to forward, so 'X' forwards the data packet. Nodes ‘Y’ and ‘V’ would receive a copy of the same data packet forwarded by ‘X’ and thus discards the data packet and eliminates duplicate forwarding. Expected Distance Advancement with Delivery Probability (EDADP) is calculated using the following equation.

$$\mathrm{EDADP}(S_R, D_T, C_N) = \sum_{K=1}^{N} \left(D_{S_R,D_T} - D_{C_K,D_T}\right) \times P_{S_K,C_K} \prod_{L=1}^{K-1} \left(1 - P_{S_R,C_J}\right)$$

S_R is the source node, D_T is the destination node and C_N is the candidate list of N probable forwarder nodes. $\left(D_{S_R,D_T} - D_{C_K,D_T}\right)$ gives the expected distance progress of each candidate node to the destination. P_{S_K,C_K} gives the data delivery probability between source node and K^{th} candidate node.

Table 4.1 depicts the Forwarder Priority List for both the discussed scenarios in OOR.

Table 2. Forwarder Priority List

Src ip, Dest ip	**HPF (Based on nearness to destination)**	**RF (Based on EDADP value)**
S1, D1	C	D, B, A
S2, D2	W	X, V, Y
……………….	……..…………………….	……………………………….
……………….	…………………………….	……………………………….

Algorithm1: Constructing the Forwarder Priority List (FPL)

1. Initialization,
2. set the destination device as N_D,
3. set the Forwarder Priority List as FPL,
4. set the Neighbor Device List as NNL,
5. set the distance from the current device to the destination device N_D as CD_{DIST}
6. begin
7. if destination device is in the list of neighbors
8. then

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set destination device as the next hop device
return
end if
for j←0 to length(NNL) do
NNL[j].dist←dist(NNL[j], N_D)
end for
NNL.sort()
NNL[0]=H_F
NNL[1]=M_{F1}
NNL[2]=M_{F2}
next hop← H_F
for j←1 to length(NNL) do
if dist(NNL, ND) ≥ length of FPL or CD_{DIST}
then
break
else
FPL.add(NNL[j])
end if
end for

Thus using OOR, forwarding of the data packet is ensured as long as there is one device in the FPL leading to high data delivery rate and continuous transmission in the network. Further most of the data is forwarded by the Highest Forwarder Device (HPF) that maximizes the progress of the data packet towards the destination and also reduces the overhead and delay required for further computation. Our results show that in majority of cases the data is forwarded by the HPF. If the HPF is unable to forward the data packet within a particular time the Next Forwarder Node (NFN) is selected to forward the data packet. The NFN is selected based on the highest EDADP value that ensures minimum retransmissions because the candidate node selected has excellent distance progress and very high data delivery probability in the network. Results from Simulations

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with Network Simulator-2 shows that our method achieves very high efficiency and QoS compared to all existing opportunistic routing protocols in HDMANETs.

3. Performance Analysis

The performances of the proposed methods are analyzed using Network Siumlator-2 (NS-2). Table 4.2 summarizes the parameters used in simulation. The MAC protocol used for the simulation is IEEE 802.11g. 100 nodes are deployed in a network area of 1000×800 m^2 rectangular region. The transmission range of the nodes is set at 250 m. Constant Bit Rate (CBR) traffic is being generated from the source to the destination nodes in the network at a rate of 20 packets per second (40kbps). The size of the data packet is set as 512 bytes. The simulation starts at 100 seconds and ends at 900 seconds. Mobility in the network is created by varying the speed of nodes from 5 m/s to 50 m/s in the network. Random and dynamic movement of nodes is generated using three Random Mobility models, Random Way Point mobility model, Random Walk Mobility Model and Random Direction Mobility Model

Table 3. Simulation Parameters

MAC Protocol	IEEE 802.11g
Propagation Model	Two-ray Ground
Traffic Type	CBR
Network Area	1000x800 m^2
Transmission Range	250 m
Mobility Model	Random Way Point Mobility Model Random Walk Mobility Model Random Direction Mobility Model
Size of data packets	512 bytes
Data Rate	40 kbps
Simulation Time	800 s
Number of devices	100
Number of Simulation Runs for each scenario	10

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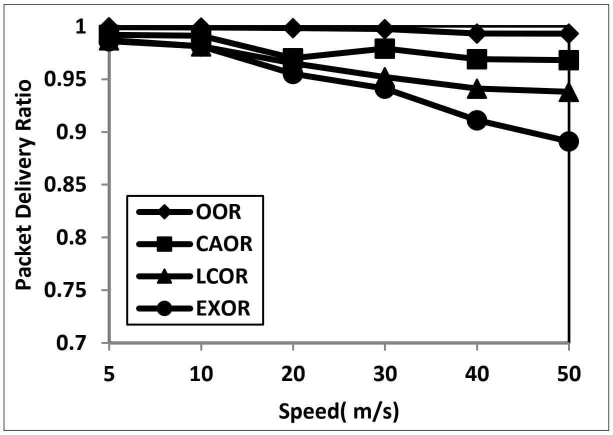
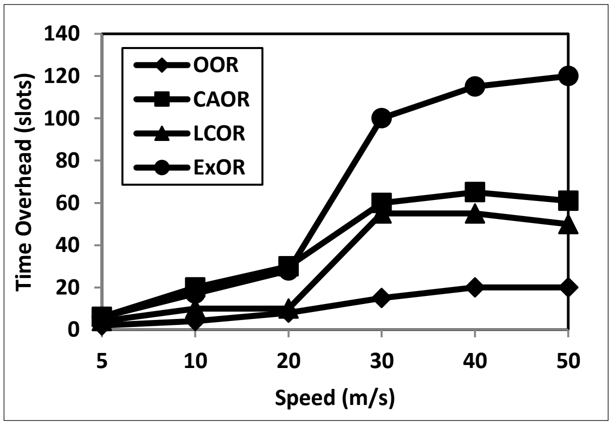
The performance of the proposed methods is compared with ExOR LCOR [49] and CAOR [48] opportunistic routing protocols. Extremely Opportunistic Routing Protocol (ExOR) is selected for comparison because it's the most referenced opportunistic routing protocol in MANETs. ExOR was one of the first protocols to utilize the opportunistic forwarding mechanism and obtained wide acceptability in opportunistic routing research. Least Cost Opportunistic Routing (LCOR) is selected for comparison because, out of all OR protocols studied; this protocol selects the optimum set of candidate devices in the network and thus has minimum number of retransmissions. Compared to all other OR protocols, this protocol achieves good data delivery in the network with minimum number of retransmissions. Delay experienced by the data packets is also very minimal in this protocol. Thus LCOR is very appropriate for comparison with the proposed methods because it offers higher Quality of Service among all other OR protocols in dynamic MANETs. Context Aware Opportunistic Routing (CAOR) is selected for comparison because it is the latest opportunistic protocol that gives maximum data delivery in the network. Of all the existing OR protocols CAOR delivers maximum number of packets at the destination. CAOR gives very good performance in communication in HDMANETs compared to other opportunistic routing protocols.

4. Results and Discussion





a. PDR vs Speed **b. Time Overhead vs Speed**

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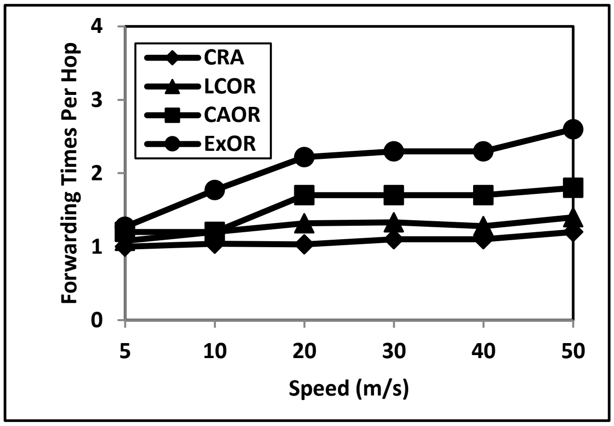

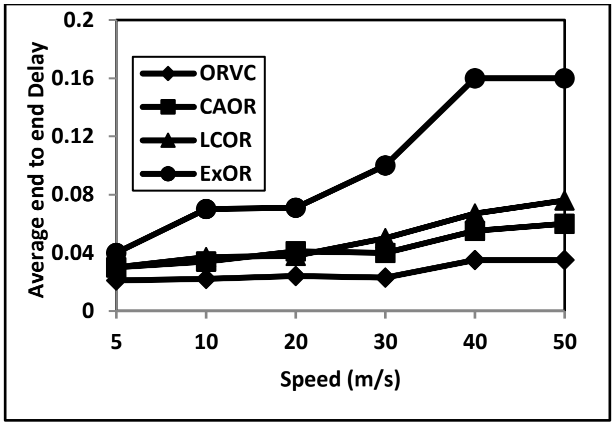

c. FTPH vs Speed **d. Average end to end delay vs Speed**

Figure 4. Simulation Results with Random Way Point Mobility Model

Figure 4 gives the performance comparison of protocols with the random way point mobility model. It is very evident that the proposed methods offer better performance to all the existing opportunistic routing protocols in highly dynamic ad hoc networks. The same could be interpreted from figure 5 and figure 6 which displays results with random walk and random direction mobility models respectively.

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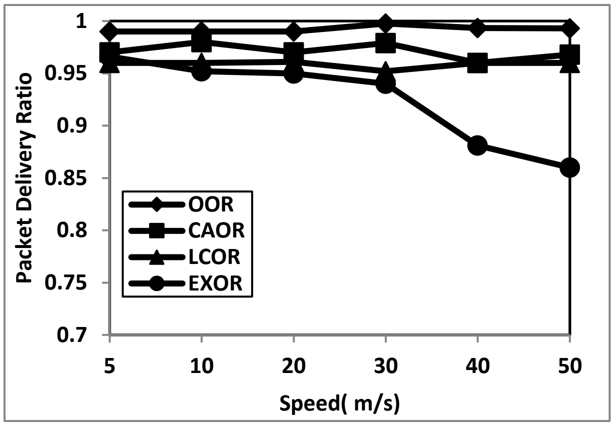
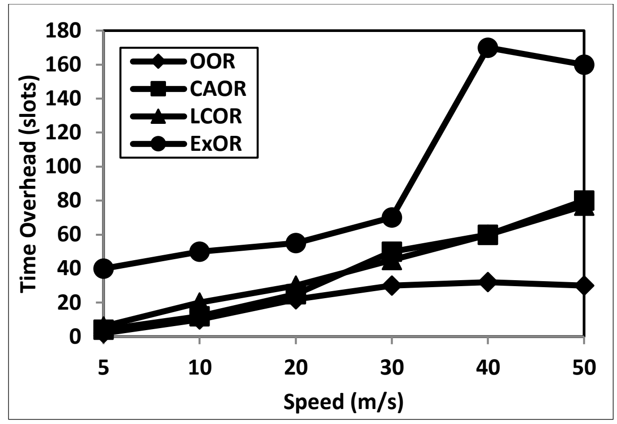
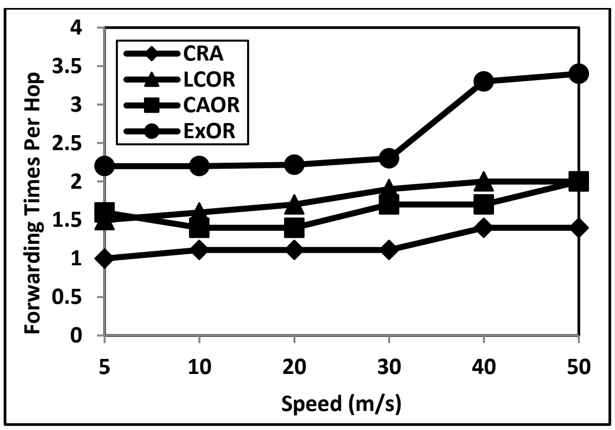
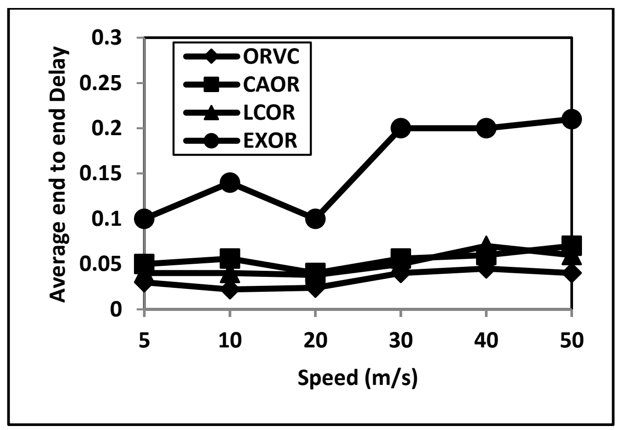




a. **PDR vs Speed**

b. **Time Overhead vs Speed**





c. **FTPH vs Speed**

d. **Average end to end delay vs Speed**

Figure 5. Simulation Results with Random Walk Mobility Model

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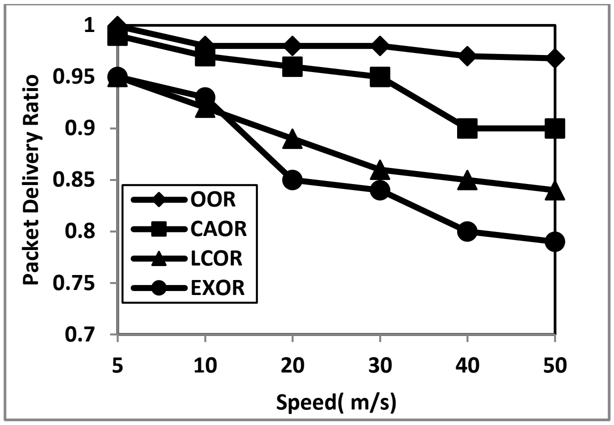
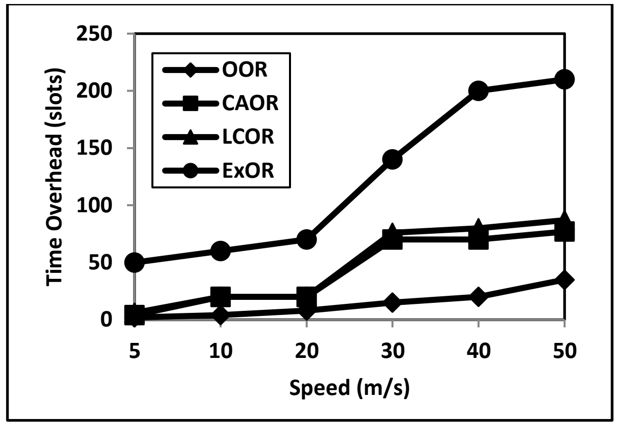
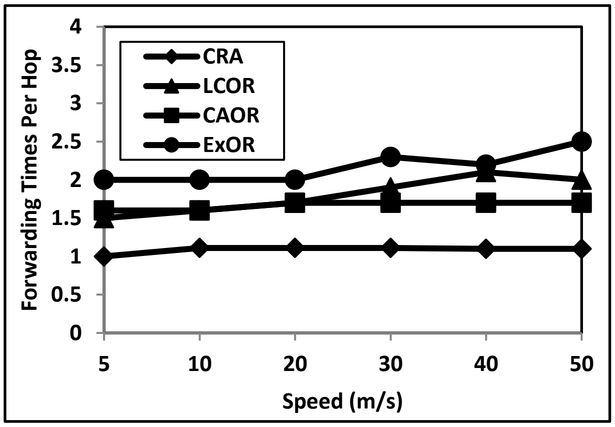


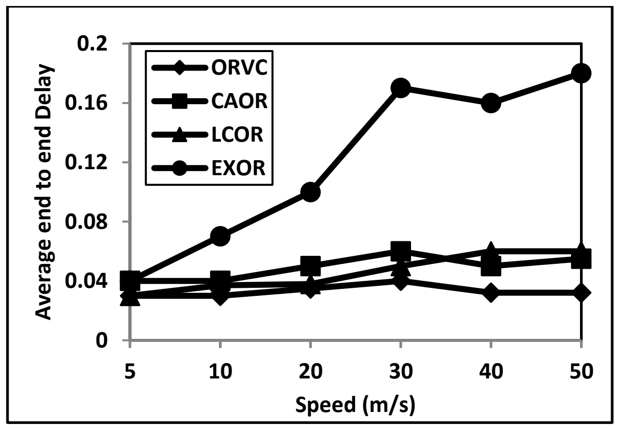
a. PDR vs Speed



b. Time Overhead vs Speed



c. FTTH vs Speed



d. Average end to end delay vs Speed

Figure 6. Simulation Results with Random Direction Mobility Model

5. Conclusion and Future Research Directions

As the speed and mobility of devices increases in the network, performances of the existing opportunistic routing protocols degrade considerably, leading to reduced Quality of Service and poor transmission efficiency. The exceptional potential of opportunistic routing is thus underutilized. Redundant data forwarding at the intermediate nodes, high time overhead from frequent packet retransmissions and inefficiency in handling communication voids are the reasons contributing to this transmission inefficiency. The paper proposed Optimized Opportunistic Routing (OOR) strategy that guarantee excellent Quality of Service and high transmission efficiency to the latest applications using opportunistic routing for communication in highly dynamic ad hoc networks. Simulation results showed that our method achieve significant performance improvements compared to all other existing opportunistic routing protocols in highly dynamic mobile ad hoc networks. Further these methods could also be implemented for routing in Internet of Things [42-44] underwater swarm robots [45] and vehicular fog networks [46-47].

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