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Multipath Routing Protocol for Reliable Data Transmission over Infrastructure-Less Mobile Network

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***Abstract* - Providing requisite QoS guarantees in wireless multihop networks is much more challenging than in wired networks. This is mainly due to its dynamic topology, multihop communication and contention for channel access. In particular, it is important for routing protocols to provide QoS guarantees by incorporating metrics like achievable throughput, delay, jitter, packet loss ratio, etc. In this paper, we have proposed and implemented a node-disjoint multipath routing protocol (NM-On Demand Distance Vector) based on on-demand distance vector routing protocol for reliable and efficient routing over Mobile Networks. Our proposed multipath protocol discovers all node-disjoint routes between a source and destination within a single route discovery phase. To prove the correctness and effectiveness of proposed approach, it is compared with other traditional routing protocols. Simulation results are provided which are generated using the Qualnet simulator for various scenarios to show the effectiveness of proposed approach.**

***Keywords*- Multimedia Streaming, Routing Protocols, QoS, MPEG-4, Video Quality, Performance Evaluation, Qualnet v5.**

I. Introduction

Mobile networks are collection of mobile hosts which can self-configure, self-organize and, self-maintain while communicating with each other through wireless channels in having no centralized control. The inherently infrastructure less, inexpensive and quick to deploy nature of mobile network is providing a promise for its use in diverse domains. Starting from late 1990s mobile ad hoc networks gained a huge popularity among people because of their infrastructure less, independent, inexpensive, live and on-the-fly nature. In mobile network one of the important open issues is routing i.e finding a suitable path from source to destination. Due of the rapid growth in use of applications like online gaming, audio/video streaming, VOIP and other multimedia streaming applications in mobile network, it is mandatory to provide some desired level of quality of service (QoS) for reliable delivery of data and/or quality. Providing required QoS guarantees in wireless multihop networks is much more challenging than in wireline ones mainly due to its dynamic topology, distributed nature, interference, multihop communication and contention for channel access. In particular it is important for routing protocols to provide some sort of QoS guarantees by incorporating few QoS metrics like achievable throughput, delay, jitter and packet loss ratio.

Despite the large number of routing solutions available in mobile networks, their practical implementation and use in real world is still limited. Multimedia and other delay or error sensitive applications that attract a mass number of users towards the use of mobile networks realized that best effort routing protocols are not adequate for them. Because of the dynamic topology and physical characteristics of mobile networks providing guaranteed QoS in terms of achievable throughput, delay, jitter and packet loss ratio is not practical. So, QoS-adaptation and soft-QoS is proposed instead. Soft-QoS means failure to meet QoS is allowed for certain cases, such as, when route break or the network becomes partitioned [1]. If nodes mobility is too high and topology changes very frequently providing even soft-QoS is not possible. So, for a routing protocol to function properly in a wireless network where mobility is high the rate of topology state information propagation must be higher than the rate of topology change. Otherwise the topology information will always be stale and inefficient routing will takes place or may be no routing at all. This applies equally to QoS state and QoS route messages. A network that satisfies the above condition is said to be combinatorial stable [2].

This paper is organized in the following manner. In Section II, we present the related work done in the area of mobile networks multipath routing. In Section III, we present our proposed node-disjoint multipath routing protocol and discus it in detailed manner with an example. In Section IV, we provide the simulation results and evaluate the performance of proposed method over different network scenarios. Finally, conclusion of the presented work and its related future work is given in Section V.

II. Related Work

In [3], author proposes an Ad hoc On-demand Distance Vector Multipath Routing Protocol with Path Selection Entropy (AODVM-PSE). Compared to the conventional multipath extension on on-demand multiple distance vector routing protocol (AODVM), AODVM-PSE assigns the construction of multiple paths to the destination node and makes it algorithmically simple, resulting in the improved performance of packet delivery, average end-to-end delay and control packets ratio incurred at intermediate nodes.

The Multipath routing problem of mobile networks with multiple QoS constraints, which may deal with the delay, bandwidth and reliability metrics, and describes a network model for researching the routing problem is presented by authors in [4]. It presents a Node-Disjoint Multipath routing protocol with multiple QoS constraints (NDMRP). The NDMRP successfully solves the QoS routing problems when nodes change dynamically in the

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networks. It only requires the local state information of the link (or node), but does not require any global network sate to be maintained. It can effectively decrease the overhead for the network lifetime, and improve the success ratio of seeking links evaluation.

In [5], authors propose Time Delay On-demand Multipath (TIDOM) routing protocol accommodates the time delay function in flooding RREQ packets. The time delay function is inversely proportional to the residual battery capacity of intermediate nodes themselves. This function avoids nodes with poor residual battery capacity, and promotes nodes with good residual battery capacity joining the routes. Simulation results show that TIDOM improves the network lifetime, energy consumption, and additionally packet delivery ratio over the Ad hoc On-demand Multipath Distance Vector (AOMDV).

Also in [6], authors propose multipath routing protocol establishes node disjoint paths that have the lowest delays based on the interaction of many factors from different layers. Other delay aware mobile networks routing protocols don't consider the projected contribution of the source node that is requesting a path into the total network load. The implication is that end to end delay obtained through the RREQ is not accurate any more. Furthermore, in [7] authors present an approach that contains an adaptive rate control based technique in which the destination node copies the estimated rate from the intermediate nodes and the feedback is forwarded to the sender through an acknowledgement packet. Since the sending rate is adjusted based on the estimated rate, this technique is better than the traditional congestion control technique.

III. Proposed Node-Disjoint Multipath Routing Protocol

The Node-Disjoint Multipath Routing based on on-demand distance vector routing protocol [8] (NM- on-demand distance vector routing protocol) protocol proposed here is novel: it can efficiently discover multiple route paths between nodes desiring communication with minimal control overhead (low broadcast redundancy) and minimal outing latency. This section shows the protocol's mechanism in detail.

A) Route Discovery Phase of NM- on-demand distance vector routing protocol

When a source node wants to communicate with a destination node, it checks its route table to confirm whether it has a valid route to the destination. If so, it sends the packet to the appropriate next hop towards the destination. However, if the node does not have a valid route to the destination, it must initiate a route discovery process. To begin such a process, the source creates a RREQ (Route Request) packet. This packet contains message type, source address, current sequence number of source, destination address and the broadcast ID. The broadcast ID is incremented every time when the source node initiates a RREQ. In this way, the broadcast ID and the address of the source node form a unique identifier for the RREQ.

Figure 1 shows the flow chart of initiating a discovery process. Finding node-disjoint multiple paths with low broadcast overhead is not an easy task when the network topology is unknown and changing dynamically. This section briefly describes the mechanism of NM- on-demand distance vector routing protocol based on on-demand distance vector routing protocol that discovers multipath routes during the route discovery process and records the shortest routing hops to minimize its routing overhead and achieve multiple node-disjoint routing paths. NM- on-demand distance vector routing protocol routing computation has two key components to avoid introducing a routing overhead and provide reliable routing in mobile networks : a) Decreasing routing overhead packets and, b) Selecting node-disjoint paths.

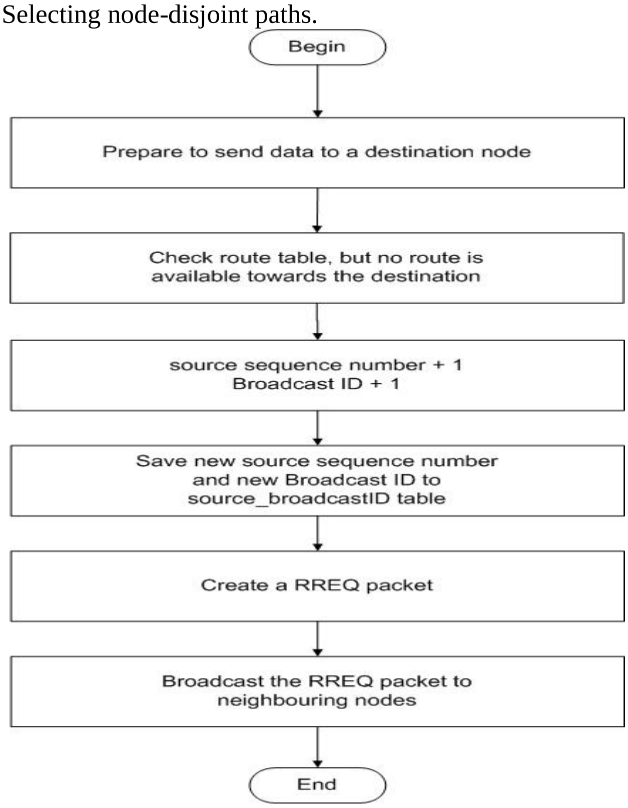

Fig.1. Flow Chat of Route Discovey Process

The main goal of NM- on-demand distance vector routing protocol is to build multiple node-disjoint paths with a low routing overhead during a route discovery. To achieve this goal, the source node should store the multiple routes for the destination in its routing table so that when the primary route is broken the source can use the secondary route for continues data transmission without initiating the discovered during route discovery phase are node-disjoint. This minimizes the possibility that the secondary route is also broken when the primary route is broken. Therefore, on-demand distance vector routing protocol is modified to include node-disjoint multipath route discovery mechanism.

When a RREQ packet arrives at its destination, the destination generates a Route Reply (RREP) packet irrespective the fact that the received RREQ is duplicate or not and unicasts it back towards the source that originated the RREQ message along the reverse route path. When an

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intermediate node receives a RREP, it updates its routing table entry based on the information in the received RREP packet. The intermediate node only forward the RREP, if it is not a duplicate based on the value of Isduplicate_RREP field of Node_broadcastID table. In this way, the intermediate node's only forward a RREP if its forwarding will not violet the protocols node-disjoint route property. Algorithm 1 shows the detailed process of our proposed multipath routing approach and how it handles the RREQ and RREP packets at each node in the network.

B) Proposed Pseudo code with an Example

In this sub-section, we present the proposed methods pseudocode and explain its working with the example given below.

Pseudocode for NM-on-demand distance vector routing protocol

```
// S is the source node; D is the destination node
// RT = Routing Table; NT = Node_broadcastID table
IF (S wants to communicate with D)
IF (RT of S contains a route to D)
S establishes communication with D
ELSE
S creates a RREQ packet and broadcasts it to its neighbors
ENDIF
ENDIF
// RREQ contains the destination Address (DestAddr),
// Sequence Number (Seq) and Broadcast ID (BID)
IF (N receiving RREQ && N != D)
IF (RREQ was previously processed)
Discard duplicate RREQ
ELSE
IF (N == D)
Initialize the extra field of RREP (i.e. FloodingID) with the
BroadcastID value of the received RREQ
send back a RREP packet to the node sending the RREQ
ELSE IF (N has a route to D with SeqId >= RREQ.Seq)
Do nothing because intermediate nodes are not allowed
to send RREP messages
END IF
END IF
WHILE (N receives RREP && N != S)
IF (Received RREP is not a duplicate (check using the value of Isduplicate_RREP field in NT))
Forward RREP on the reverse path
Store information about the node sending RREP in the RT
ELSE
Discard the RREP without forwarding
END WHILE
IF (S receives RREP)
S updates its RT based on the node sending the RREP
S stores the route as primary or secondary based on the whether it is a fresh RREP or duplicate one
S establishes communication with D
END IF
```

The working of the proposed Algorithm is explained using an example shown in Figure 2. Suppose, node S is the source node and node D is the destination node. When node S has data to send, it initiates the route discovery process by flooding the RREQ in the network. Let us assume that destination D receives its first RREQ from intermediate node I at time t1. According to Algorithm 1, upon the reception of a RREQ message, destination node has to initiate the RREP message. So, node D initiates the RREP1 message. This RREP1 is unicast towards source S on the reverse path $D \rightarrow I \rightarrow H \rightarrow B \rightarrow S$. When RREP1 is received by an intermediate node along the reverse route, each intermediate node resets the value of Isduplicate_RREP in its seen table.

Suppose, D receives the first duplicate RREQ message from J at time t2. Again, node D initiates a RREP2 for this duplicate RREQ and sends it back towards node S through the same path it came to D (i.e. $S \rightarrow A \rightarrow F \rightarrow J \rightarrow D$) to make the reverse route i.e. $D \rightarrow J \rightarrow F \rightarrow A \rightarrow S$. This helps to create a forward route towards node D. Finally, say at time t3, node D receives the third duplicate RREQ message from node K. Node D initiates RREP3 for this duplicate RREQ and sends it towards S through K. The RREP3 reaches node J through K. Node J checks the value of Isduplicate_RREP for RREP3 and determines that the Isduplicate_RREP is set to TRUE. So node J considers RREP3 as a duplicate RREP message and drops it.

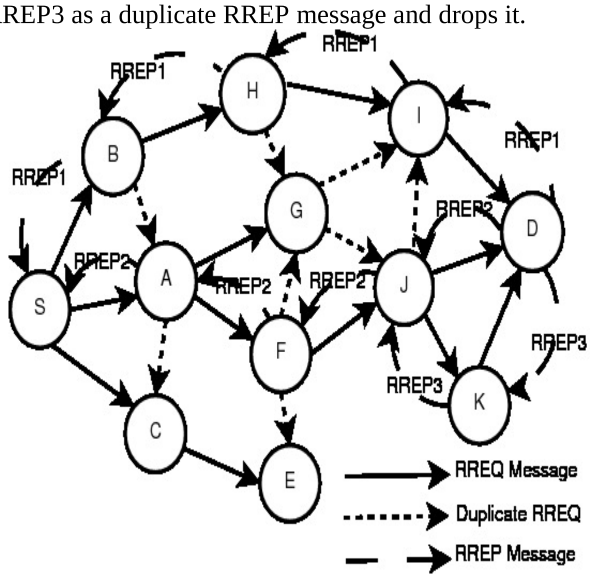

Fig.2. Multipath Route Discovery Process

C) Route Maintenance Process

In general, route links in ad hoc networks are broken frequently due to the mobility of nodes, congestion and packet collisions. Like on-demand distance vector routing protocol, each node of NDMR is dependent on sending out HELLO packets to maintain local connectivity. Failure to receive a HELLO packet from a neighbor is regarded as an indication that the link to the neighbor is broken. A Route Error (RERR) packet is propagated from the upstream node of the link failure to the source node for the route. When an intermediate node receives a RERR packet, it marks its route to the destination invalid and then propagates the RERR to its precursor node along the reverse route path. After receiving the RERR, the source invalidates the route path to destination and chooses a valid node-disjoint routing path as active routing path from the routing table to continue to forward data packets. Additionally, the source needs to check each valid flag of the three node-disjoint route paths. If only one of them is valid or all of three routing paths are invalid, the source initiates a route discovery process.

Route maintenance process is invoked when an active route is broken during completion of a data flow. When the primary route is broken, transmission of data is continued using the secondary routes. To keep the secondary routes active while using the primary route, we increase the lifetime of each active secondary route after a fixed amount of time. When all the secondary routes are also broken, the source starts a new route discovery process. In this way, we can minimize the routing overhead caused in finding and maintaining multiple routes. Because in this case, only one RREQ is used to find all available node-disjoint paths as compared to one RREQ required for each path, as in the case of traditional on-demand distance vector routing protocol.

III. Simulation and Performance Evaluation

In this section, we analyze the performance of our proposed routing protocols and show its effectiveness and correctness using simulation results.

A.Simulation Environment

Qualnet 5.0.1 Modeler [9] was used to create a simulation environment to develop and analyze the proposed NM- on-demand distance vector routing protocol and compare its performance with the already existing on-demand distance vector routing protocol and DSR [10] on-demand unipath ad hoc routing protocols.

The mobility and traffic models similar to those previously reported are used. The random waypoint model is used to model mobility of nodes. This model was first used by Johnson and Maltz in the evaluation of DSR, and was later refined by the same research group. Each node starts its journey from a random location to a random destination point with a specific speed. Once the destination is reached, another random destination point is targeted after a pause. Field configurations of 1000m x 1000m field with 50 nodes. Each node uses the IEEE 802.11b with a 250m transmission radius. The pause time of mobile nodes is kept constant at 30 seconds for all the simulation experiments.

Traffic sources with 512 bytes data packets are CBR (constant bit rate). The source-destination pairs are spread randomly over the network and the number of sources is varied to change the offered load in the network. The sending rate is set to 30 packets per second that means the inter-packet time at source node is set to 33 milliseconds. Nodes in all the three protocols maintain a send buffer which can contain 100 packets. Each node buffers all data packets while waiting for a route. All packets (both data and routing) sent by the routing layer are queued at the buffer until the MAC layer can transmit them. Routing packets are given higher priority than data packets in the buffer.

Simulations are run for 500 simulated seconds. Each data point represents an average of five runs with identical traffic models, but different randomly generated mobility scenarios by using different seeds. The maximum and minimum values are also shown on the graphs.

B. Simulation Results

In order to compare and evaluate performances of the three protocols (NM- on-demand distance vector routing protocol, on-demand distance vector routing protocol and DSR) in different network conditions, three parameters are varied in the simulations:

- Maximum mobility of the nodes
- Maximum number of sources

At first, simulations are carried out by keeping the number of sources constant and varying the mobility in the network. 5 sources are modeled respectively to study the effect of varying mobility in network. Then, the number of sources is varied from 1 to 10. When varying the number of sources, node's mobility is kept random between 0 to 10 m/s.

1) Effect of network mobility

The first set of experiments varies the velocity for 5 sources of 50 nodes network. The mobility was varied to see how it affects the different metrics that are measured. The packet sending rate is fixed at 30 packets / sec. The results are collected at constant speeds of 5, 15, 25, 35, 45 and 55 m/s.

The packet delivery ratio of the three protocols is shown in Figure 3. The Figure depicts the variation of the packet delivery ratio as a function of mobility of nodes. As the mobility of the nodes increases, the probability of link failure increases and hence the number of packet drops also increases.

NM- on-demand distance vector routing protocol has much higher packet delivery ratio than both on-demand distance vector routing protocol and DSR. More than 75% data packets of NM- on-demand distance vector routing protocol can be delivered to specified destinations in all of mobility conditions. on-demand distance vector routing protocol and DSR have a similar low delivery ratio situation in that only 60% sent packets are received at higher speeds. The reason is that NM- on-demand distance vector routing protocol has multiple paths with node-disjointness. When an active routing path (i.e. primary route) is broken due to mobility of nodes, the source node of the data flow will receive a notification of link break. The source node at once invalidates the broken routing path in its route table and selects another valid node-disjoint routing path (i.e. secondary route) from its route table to continue to keep communication between source and destination without pause or interrupt. In addition, when there only remains a routing path available to forward data packets in the route table of a source node, the source will initiate a discovery process to get a new set of multiple paths.

Figure 4 depicts the variation of the average end-to-end delay as a function of the mobility of nodes. The delay of NM- on-demand distance vector routing protocol remains approximately equal at all mobile velocities. Delay in DSR and on-demand distance vector routing protocol increases quickly as velocity increases. When the velocity is more than 15m/s, the delay in NM- on-demand distance vector routing protocol is almost half of that in on-demand distance vector routing protocol and DSR. This is because availability of alternate node-disjoint routing paths in NM- on-demand distance vector routing protocol eliminates route discovery latency that contributes to the delay when active route fails. In addition, when a congestion state occurs in a routing path, the source node can distribute incoming data packets to the other node-disjoint routing paths to avoid congestion. This reduces the waiting time of data packets in queue.

Figure 5 normalized routing load characteristics of the network. It can be seen that the normalized routing load in NM- on-demand distance vector routing protocol performs much better than that of both on-demand distance vector routing protocol and DSR. The metrics increases slowly with the increase of velocity. The normalized routing load in on-demand distance vector routing protocol and DSR increases more quickly than that in NM- on-demand distance vector routing protocol with the increase of velocity.

2) Effect of increase in network traffic

The experiment varies the number of sources with a random velocity of 0-10 m/s in this section. The network load is varied by changing the number of sources. The packet sending rate is still fixed at 30 packets / second. The number of sources is varied from 1 to 10 in intervals of 10 for 50 nodes.

The packet delivery ratio of the three protocols is shown in Figure 6. The Figure describes the variation of the packet delivery ratio as a function of the number of sources. It can be seen that the packet delivery ratio for NM- on-demand distance vector routing protocol has much better performance than those of both on-demand distance vector routing protocol and DSR with the increase in the number of sources. When the number of sources increases, on-demand distance vector routing protocol and DSR drop a larger fraction of the packets. Although the delivery ratio of NM- on-demand distance vector routing protocol is more than 70%, it decreases more quickly with larger numbers of sources. The reason is that there are more collisions in the air and congestion in node buffers when the number of sources increases.

Figure 7 depicts the variation of the average end-to-end delay as a function of the number of sources. It can be seen that NM- on-demand distance vector routing protocol has a lower average delay than both on-demand distance vector routing protocol and DSR under almost all possible numbers of source. The primary reason is that the number of route discoveries is reduced in NM- on-demand distance vector routing protocol. Although NM- on-demand distance vector routing protocol has a low number of route discoveries, its delay also increases gradually with the increase of number of source. The reason is that increase of the numbers of sources leads to higher network load traffic in the ad hoc networks. Because of the limitation of a constrained wireless bandwidth, packets that will be sent or forwarded have to stay in buffers and wait for a longer time to get a radio channel available in order to avoid collisions in the air.

The normalized routing load of the three protocols is shown in Figure 8. The Figure depicts the variation of normalized routing load as a function of the number of sources. With the increase of the number of sources, the probability of packet collision and packet congestion increases. This leads to the increase of normalized routing load. It is seen that NM- on-demand distance vector routing protocol has much lower normalized routing load than both on-demand distance vector routing protocol and DSR in all possible numbers of sources. The normalized routing load in on-demand distance vector routing protocol and DSR increases more quickly than that in NM- on-demand distance vector routing protocol with the increase of the number of sources. The reason is that NM- on-demand distance vector routing protocol has multiple node-disjoint paths.

IV. Conclusion and Future Work

In this paper, we have presented a low routing overhead node-disjoint multipath routing protocol based on reactive routing protocol on-demand distance vector routing protocol. The simulations results show that having more than one route for a destination on a source node. The data communication is affected less due to route breaks if the backup route is active when the primary route is broken. We have shown through simulation that finding and maintaining multiple routes at source nodes greatly increases the packet delivery ratio and decreases the end-to-end delay of a data flow. The node- disjoint property of our multipath routing makes the secondary routes less affected by the failure causes happens on primary route and therefore increases the probability that the secondary routes are available when primary routes are broken.

In the future, we will relax the node-disjointness property to provide more chances to find the secondary routes in the network. Also, we will check how the load-balancing will work on multiple routes with its advantages and disadvantages.

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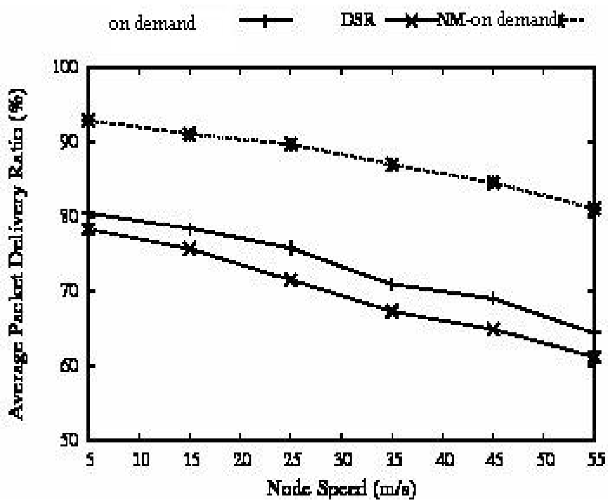

Fig.3. Effect of network mobility on PDR

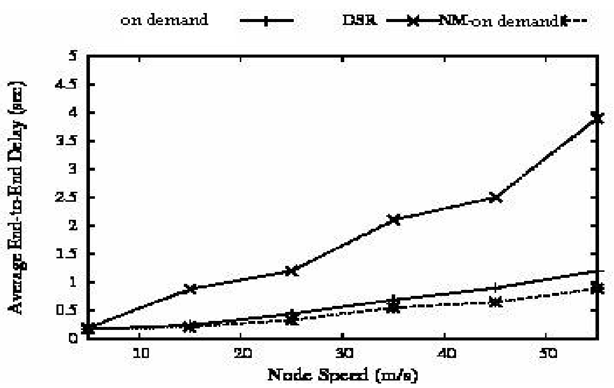

Fig.4. Effect of network mobility on EED

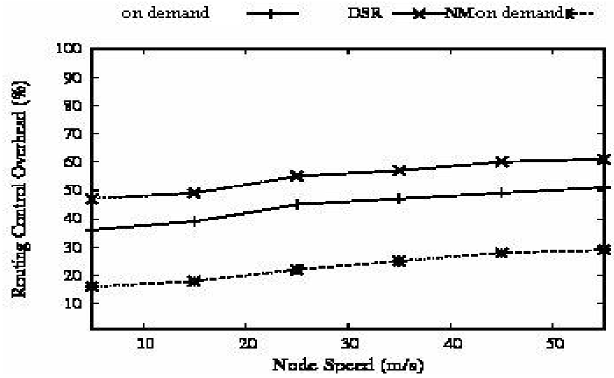

Fig.5. Effect of network mobility on RO

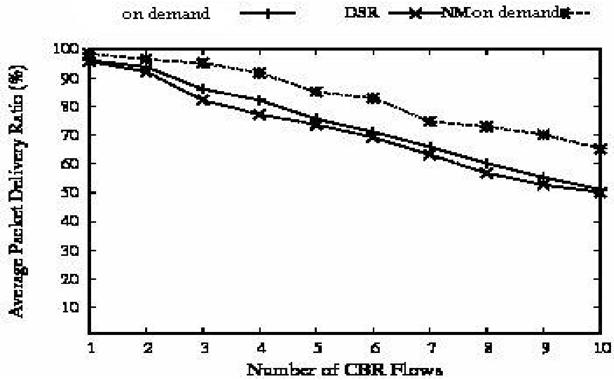

Fig.6. Effect of increase in sources nodes on PDR

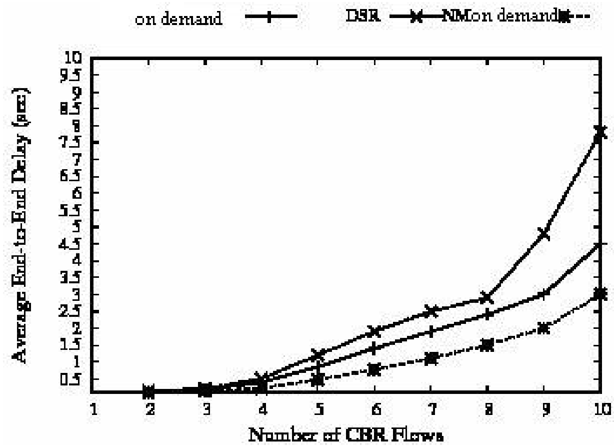

Fig.7. Effect of increase in sources nodes on EED

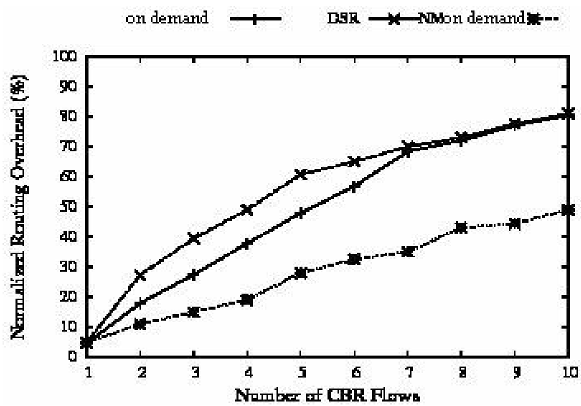

Fig.8. Effect of increase in sources nodes on RO