Design and Analysis of Hybrid On-demand Node Disjoint (HOND) Multipath Routing Protocol for Mobile Ad hoc Networks.

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***Abstract*—In this paper, the authors propose a novel multipath routing protocol, which makes use of neighbor knowledge and uses adaptive *HELLO* messaging scheme in combination with node disjoint multipath routing. The proposed scheme chooses the parameters such that they all complement each other and enhances the overall routing performance of the network. The neighbor knowledge assigns order of forwarding of control packets and adaptive *HELLO* messaging scheme dynamically changes the *HELLO* interval. Combining them with a node disjoint multipath routing scheme based on energy of the nodes, results in a routing protocol which is diverse and universal in its network applications.**

***Index Terms* - Ad hoc, AODV, node-disjoint, MANET, rebroadcast, RREQ, routing overhead.**

I. Introduction

Networks are set of connections between nodes. These nodes can be a source, destination, intermediate, idle or logical combination of two or more such cases. The network provides medium for transmission of data from source node to destination node using intermediate nodes. There may be various paths available between source and destination, but there is only one optimum path. This optimum path is decided based on minimum number of hops, that the data has to pass through, in order to reach from source to destination. The source node initiates a route discovery process by sending control packets (RREQ) towards the destination using intermediate nodes. Destination node acknowledges the source if there is an availability of path to it. On the basis of this acknowledgement, the source node decides which is the optimum path for fast and secure data transmission. Finding the optimized path using minimum resources in quick time, is the main aim of routing mechanism. There are several routing protocols [1] and proposals, for optimized route finding, but most of them fall short of expectation, because of their lack of universality in implementation in dynamic networks.

In case of Mobile Ad-hoc Networks (MANET), the nodes keep on moving. So there is no fixed topology of the network and the neighbors keep on changing [2]. In such highly dynamic scenario, the routing is a resource hungry and complex task, because as the nodes move, there are frequent link failures and frequent route discoveries. This results in significant amount of overhead and increased end to end delay. The collision of control packets and broadcast storm problems are other things to concern by. There are on demand routing schemes [3] available, but significant overhead and end to end delay makes them unattractive for resource and energy centric applications.

To achieve good routing performance the main concern is to make it less resource hungry and lightweight. That can be achieved by reducing routing overhead and end to end delay. For reducing routing overhead, there are a lot of proposals [4], which are location based, energy based and neighbor knowledge based. But none of the proposals are able to achieve a certain amount of performance level on its own. This paper proposes the combining of neighbor coverage based approach [5] with the adaptive *HELLO* messaging scheme [6] and multipath routing. The metrics are chosen and interleaved in such a manner that the designed protocol works as a standalone protocol and help us counter major routing deficiencies such as flooding of control packets.

II. Related Work

With the advancement of technology, there are more mobile and handheld devices are in use than ever before. There is a great scope of improvement in terms of routing performance of such mobile networks, because the overhead and packet delivery ratio of acceptable levels can be difficult to achieve. The routing overhead of such networks can be quite large because of the fact that frequent link failures calls for frequent route discoveries, which result in significant overhead [7]. Also packet delivery ratio is also decreased and end to end delay is increased. All in all, mobile networks are more difficult to serve with as compared to a static network due to its dynamic nature. All these has resulted in a great interest among researchers about developing and proposing different routing approaches.

To work out the right combination of approaches, researches keeps on mixing and matching metrics to achieve a better routing protocol. These combinations may not always perform as expected in all the network conditions, because there is tradeoff between several performance parameters. Not all the metrics perform as desired in all network situations and environment. So there is a lack of universality of application. Also choosing and combining them is a complex task.

Xin Ming Zhang [8] came up with a novel probability based approach. It proposes the use of neighbor coverage knowledge to reduce routing overhead in MANET. It uses probabilistic and delay based approach, which assigns a forwarding order to the nodes to avoid broadcast storm problem. This approach is attractive in case of low to medium mobility of the network. The delay and probability based approaches are interlinked with each other by the use of uncovered neighbor set. X.M. Zhang [9] proposed a proposed a probability and distance based approach, which also concentrates on reducing routing overhead in highly dynamic networks. The combining of such parameters is the key of success for the routing protocol.

HELLO messaging scheme is the key for the dissemination of neighbor knowledge and finding out the information about the availability of the link in the network, but it adds on to the overhead. There is a need of suppression of overhead caused by *HELLO* messages. The already proposed systems [10] [11] include techniques of optimisation of number of *HELLO* messages or the frequency of messaging between neighbors. The results have shown significant reduction in overhead caused by *HELLO* messages, but the adverse affect on other parameters in quite prominently significant. There is a scope to reduce the adverse effect of adaptively adjusting the *HELLO* messages. The selection of parameters and the application specific environment are also the areas of consideration.

Multipath routing has several advantages but is not widely deployed in industry applications because of its lack of dynamicity. To overcome that hurdle approaches have been proposed [12]. Which takes care of overall routing performance of the network. For MANET applications, where nodes move in bunch, the multipath routing needs to be adjusted to provide node disjoint paths [13]. There are complexity issues with deployment of multipath routing. But there are simple approaches which can be clubbed together to provide the much needed dynamicity. To solve out the complexity issues the lightweight approach is needed.

III. Hybrid On-demand Node Disjoint (HOND) multipath routing protocol

In this section we define the designing of approaches with their algorithms. The metrics that are being used, their role in the network and their functionality, all are taken care of in this section. Here we also explain how the each approach is related to other and complement each other. The principle of approaches and their strategic inclusion also gives an intimation about their effect on expected results as well.

A. Neighbor Coverage (NC) based approach

Neighbor coverage based approach combines both neighbor coverage and probabilistic methods. In order to effectively exploit the neighbor coverage knowledge, we need a novel rebroadcast delay to determine the rebroadcast order, and then we can obtain a more accurate additional coverage ratio. In order to keep the network connectivity and to reduce the redundant retransmissions, we need a metric named connectivity factor to determine how many neighbors should receive the RREQ packet. After that, by combining the additional coverage ratio and the connectivity factor, we introduce rebroadcast probability, which can be used to reduce the number of rebroadcasts of the RREQ packet and to improve the routing performance.

- *Rebroadcast Delay:*

To make productive use of neighbor knowledge, the key to success is that it must be disseminated quickly within the network. For example, suppose a node n_0 forwards a RREQ to all its neighbors n_i (where i =1,2,3…n), all the nodes processes the RREQ and find out about the number of common nodes with n_0, by using neighbor list included in the RREQ. Out of all the neighboring nodes assume that n_k has the most number of common neighboring nodes with n_0. As a result of which rebroadcast delay for n_k is set the lowest and is given the priority in forwarding of RREQ. Node n_k rebroadcasts this RREQ to its neighbors with a rebroadcast probability, which we will discuss in the next subsection and the process continuous, until RREQ reaches its destination node. The primary objective of setting rebroadcast delay and assigning the forwarding priority to nodes is to quickly disseminate the neighbor knowledge within the network, rather than forwarding it to more number of nodes. On the basis of the beforehand information about the neighbor knowledge, each node can quickly make decisions regarding assigning forwarding priority to neighboring nodes for the next time onwards.

Algorithm 1: The algorithm describes the rebroadcast delay description for the intermediate node n_i.

```
Rebroadcast Delay ()
{
IF node n_i receives RREQ from previous node n_0
Use neighbor list table to see the uncovered neighbors from s
THEN
IF RREQ comes for the first time
Find neighbor node knowledge
ELSE
Discard RREQ message
END IF
FOR every RREQ node s sends RREQ to neighbors of n_i, i=1, 2…
DO
Assume n_k has lowest delay
n_k will rebroadcast based on Rebroadcast Probability which is find from Algorithm 2
END FOR
END IF
}
```

- *Rebroadcast Probability:*

Every forwarding node forwards the data with a certain probability of reaching to more number of nodes. Rebroadcast delay calculation involves the use of uncovered neighbors from the previous broadcast, local node density and connectivity metric, all of which give an intimate information about the fact that how well connected the forwarding node is with neighboring nodes.

On the basis of forwarding order, the neighbor knowledge is disseminated in the network and by using this knowledge each node sets its timer. While the timer runs, it updates the list of uncovered neighbors. Once the timer stops, each node end up having one final set of uncovered neighbor. Nodes which make it to the final set of uncovered neighbors are the ones who need to receive and process the RREQ. This uncovered neighbor set is further useful for calculation of rebroadcast probability.

Now for further calculation, we define a term called additional coverage ratio (R_a), which is the ratio of new set of neighbors that are being covered with the rebroadcast to the total number of neighbors. The significance of R_a is that it provides a metric that gives up a mathematical value of new neighbors that will need to receive and process the RREQ. The key to success is that RREQ must reach as many nodes as possible for better route discovery process. Hence R_a value should be high so that more nodes are covered with the rebroadcast.

Another metric called connectivity factor $F_c(n_i)$ describes about the connecting ability of node with its neighboring nodes based on its location in the network. Feng [14] came up with an optimum number of nodes that should receive and process RREQ. Simulation results show that if a node is connected to $5.1774 \log n$ nodes (where n is the total number of nodes in the network), then probability of network being well bound and connected approaches 1 as the number of nodes in the network (n) increases. So for calculations purpose, we set the connectivity factor $F_c(n_i)$ to be $5.1774 \log n$.

The advantage of using these two metrics is that in networks where local node density is lower, then number of nodes that need to receive and process the RREQ is high. As a result of which $F_c(n_i)$ is increased, which makes the rebroadcast probability to increase as well. Conversely in a network that has high local density, needs fewer number of nodes to receive and process the RREQ to avoid broadcast storm problem. In that case $F_c(n_i)$ is automatically has lower values, which provides smaller rebroadcast probability. Conclusively, it can be said that introduction of connectivity factor provides density adaptation to the rebroadcast delay.

Algorithm 2: The algorithm describes to set the Rebroadcast Probability for intermediate node n_i.

```
Rebroadcast Probability ()
{
IF node ni receive duplicate RREQ from neighbor node nj
THEN
ni knows how many neighbors have been covered by RREQ from nj
ni adjusts its uncovered neighbor set according to neighbor list
SET a reschedule timer for node ni
IF timer expires
Node ni obtains final uncovered neighbor set
THEN Uncovered neighbor set nodes need to receive and process RREQ
FOR each uncovered neighbor set
DO
Calculate
Fc{ni}= Number of nodes that are additional covered by rebroadcast/ Total number of neighbors of node ni
IF Fc (ni) is low
THEN SET Rebroadcast Probability as high
ELSE
SET Rebroadcast Probability as low
END IF
END FOR
END IF
}
```

B. Adaptive HELLO messaging scheme

The basic idea behind the adaptive *HELLO* messaging involves setting up a timer to broadcast *HELLO* messages. the timer is based on the activeness of the nodes. this timer must be selected such that the nodes which are actively taking part in communication, is given maximum time to update their neighbor i.e. they are given more time period for *HELLO* messaging. This maximum value is equal to the average time taken by other nodes in conventional scheme. whereas nodes which are less active are updated less frequently or they have less time to update their neighbor table. This means that the timer is set dynamically based on the activeness of the node. If the timer is set too low that results in loss in info and if it set too high it will result in no reduction in overhead.

To apply this idea we must take into account the fact that less frequent updating of links may increase the probability of failure of detection P_{FD}. To calculate it we first calculate the average time interval between 2 consecutive events. If all nodes use this average time interval, the risk of transmitting through a broken link reduces, but unnecessary *HELLO* messaging is resultant. So instead of this constant *HELLO* interval we use a constant probability of failure of detection P_{FD}. As the event interval increase, the *HELLO* interval increases, and the frequency of *HELLO* messaging decreases without increasing $P_{FD.}$ Hence the *HELLO* messaging OH is decreased. and when a node sends or receives a packet the timer set to its default value so that neighbor information is maintained in the table.

We observed that majority of event intervals are less than a default *HELLO* interval of *1 sec*. [2], so there is no scope for suppression of *HELLO* messages. But when the event interval is greater than 1 *sec*., then traffics are bounded by an exponential function, which is given by following expression

$$F(x,\beta)= 1\text{-}exp^{-x/\beta} \qquad (1)$$

where
x = Average event interval > default *HELLO* interval (1 *sec*.)
β = Adaptive *HELLO* interval

From the relevancy theory, x can be interpreted as link refresh period T_d and $F(x, \beta)$ can be interpreted as probability that an event occurs before link is refreshed. So the above written equation is changed into following

$$F(x,\beta) =1\text{-} exp^{-x/\beta} = P_{FD} \qquad (2)$$

$$x = -\beta \ln (1\text{-}P_{FD}) \qquad (3)$$

So we can say that when average event interval increases as the adaptive *HELLO* interval increases, which can be written in mathematical form as

$$x \propto \beta \qquad (4)$$

Since T_d represents the time when link failure is detected. Then the relation between T_d and adaptive *HELLO* interval [6] is given by

$$T_d = (ALLOWED\ HELLO\ LOSS-0.5) \times \beta \qquad (5)$$

As we know that *ALLOWED HELLO LOSS* is a constant value. Using this and previous equations, we get

$$T_d \propto \beta \qquad (6)$$

$$x \propto T_d \propto \beta \qquad (7)$$

Above equation means that as the event interval increased above its default value, the *HELLO* interval also increases proportionally. P_{FD} is taken to be *0.2*, because then it does not affect the throughput significantly. Hence the calculation for adaptive *HELLO* interval is carried out by taking the probability of detection of failure of broken links to be *0.2*. Above mentioned adaptive *HELLO* messaging scheme has a disadvantage that the packet delivery ratio may reduce marginally, which is understandable as it uses a probability of failure in detection of broken links. So while we concentrate in reducing the routing overhead, there is a slight compromise in packet delivery ratio. To overcome which we interleave this with multipath routing.

Algorithm 3: The algorithm describes the adaptive *HELLO* messaging scheme description

1. *HELLO* Interval()
2. {
3. IF event interval<1000 *m sec*
4. THEN SET *HELLO* Interval=default *HELLO* Interval=1000 *m sec*
5. ELSE
6. SET *HELLO* interval=Adaptive *HELLO* Interval=event interval/0.44932
7. END IF
8. }

C. Node Disjoint energy based multipath routing

Multipath routing scheme is used to provide security and reliability of data delivery. Instead of using just the optimum path, it makes to use alternate paths to deliver data once the primary path is no longer available, either due to movement or exhausted nodes. To avoid the initiation of route discovery once the primary path has failed, we make use of multipath routing, in which alternate paths keep the source and destination nodes to remain connected and keep delaying the process of route request, evidently it results in reduction in overhead and increase in packet delivery ratio as the source and destination pair is always connected to each other through primary or secondary path.

To design a multipath routing protocol, we must choose between node disjoint paths and link disjoint paths. The selection parameter of the type of multipath we should use depends on the criterion of choosing the alternate path.

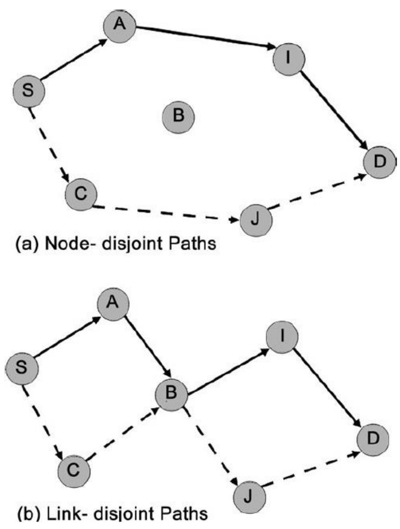

FIGURE 1: NODE DISJOINT PATHS VS. LINK DISJOINT PATHS

So now the question arises that what should be the time or event at which the path should shift from primary path to alternate path? Here we propose a scheme in which on the basis of energy of nodes, the path of communication shifts from primary to alternate and so on. We assign a threshold energy level of nodes. If any node in the existing path reaches the minimum threshold value of energy, communication shifts from optimum path to next best alternate path. There are possibilities that there exist a common node between the primary and secondary path. Once that node dies or moves out of the line of communication, alternate path also fails. This fails our energy criterion of choosing the alternate path. Hence it would be appropriate to choose node-disjoint multipath routing scheme. To achieve node disjoint paths, we have to disable the route timeout and local repair of links. Also disabling of the intermediate nodes to send RREP is needed, even if they have an active route to destination.

The number of alternate path can be selected as per need, by allowing the source node to accept multiple RREP from the destination. Multipath routing can have either node disjoint or path disjoint. Here we include node disjoint route, by disabling the local repair and route timeout. To avoid a situation where either a source or destination are dead, we must assign a lower threshold of energy to source and destination. RREP format is also altered to contain node information that with form the path. These node list is processed at the source to avoid duplication of nodes.

Algorithm 4: The algorithm describes the energy based multipath routing

```
Multipath Routing()
{
Initiate route discovery
Find optimum path
Find alternate paths
START data delivery through primary path
FOR check E_node < E_threshold
{
IF YES
START data delivery through alternate path
{
FOR check E_node < E_threshold
{
IF YES
initiate route discovery
ELSE
continue data delivery through secondary path
END IF
}
ELSE
continue data delivery through primary path
}
END IF
}
```

IV. PROTOCOL IMPLEMENTATION AND PERFORMANCE ANALYSIS

Protocol Implementation

For comparative study of the proposed protocol, we compare it with universally approved and widely used AODV routing protocol. The simulation tool used is NS-2 version 2.34. The simulation environment includes variable number of nodes ranging up to 50 nodes with different 4 different set of source-destination pairs, under different traffic conditions and queue length. We used 1 primary and 1 alternate path for communication in multipath routing.

To start implementing the proposed protocol and include the metrics and parameters of concern, we modified the source code of multipath AODV. Then enabling *HELLO* messaging to obtain information about neighbors and link failures and modified the format of RREQ, such that it can include the list of neighbors in it. We used energy model to know about the energy of the each node and apply the threshold value of the nodes to be 50% of its total energy, except for the source and destination nodes. We disabled the route timeout and local repair of links. We also disabled the intermediate nodes to send RREP, even if they have an active route to destination to make the multipath to be node disjoint. Other simulation parameters are given in table 1.

TABLE 1: SIMULATION PARAMETERS

Simulation parameter	Value
Simulator	NS-2 (Version2.34)
Propagation model	Rayleigh fading
Queue length	20
PHY/MAC	802.11
Antenna type	Omni directional
Topology size	3800m × 3800m
Bandwidth	2 Mbps
Traffic type	CBR
CBR connections	4
Simulation time	250 sec
Pause time	0.007 sec
Packet size	400 bytes
Initial energy	100
Threshold energy	50%

Performance Analysis

Routing Overhead: Number of control packets including RREQ, RREP, RERR, *HELLO* messages contributes in routing overhead. Since the size of all control packets in both the routing protocol is kept the same, hence we use number of control packets.

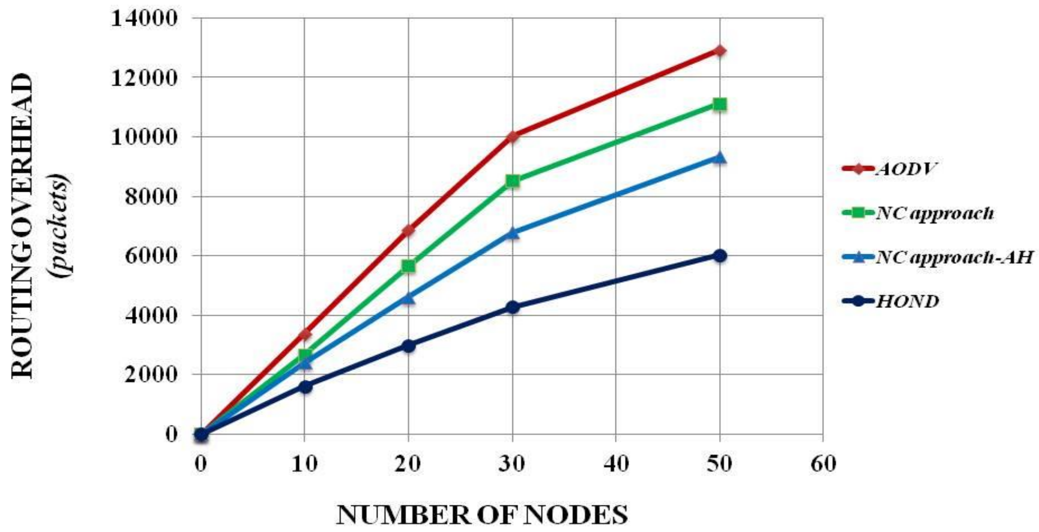

FIGURE 2: ROUTING OVERHEAD WITH VARIED NUMBER OF NODES

Fig. 2 shows the variation in routing overhead with varied number of nodes and CBR connections. From the fig. 2 we infer that as the number of nodes and CBR connections increase, routing overhead also increases. Neighbor Coverage (NC) based approach limits the redundant retransmissions of control packets, so number of routing packets are less than AODV by 7%. When NC approach is combined with adaptive *HELLO* messaging scheme, it further reduces the routing overhead by an amount of 8%.This comes as no surprise, because it reduces the overhead caused by periodic *HELLO* messages by effectively suppressing them. By inclusion of multipath routing, the number of route discovery stages are reduced and overhead associated with it are reduces conclusively. So the Hybrid On-demand Node Disjoint (HOND) multipath routing protocol reduces the routing overhead to almost half of that of AODV.

Average End to End Delay: It is the average delay experienced by all the successfully received data packets. Delays due to broken paths, queuing, unavailable links etc all are taken into account while average end to end delay is calculated.

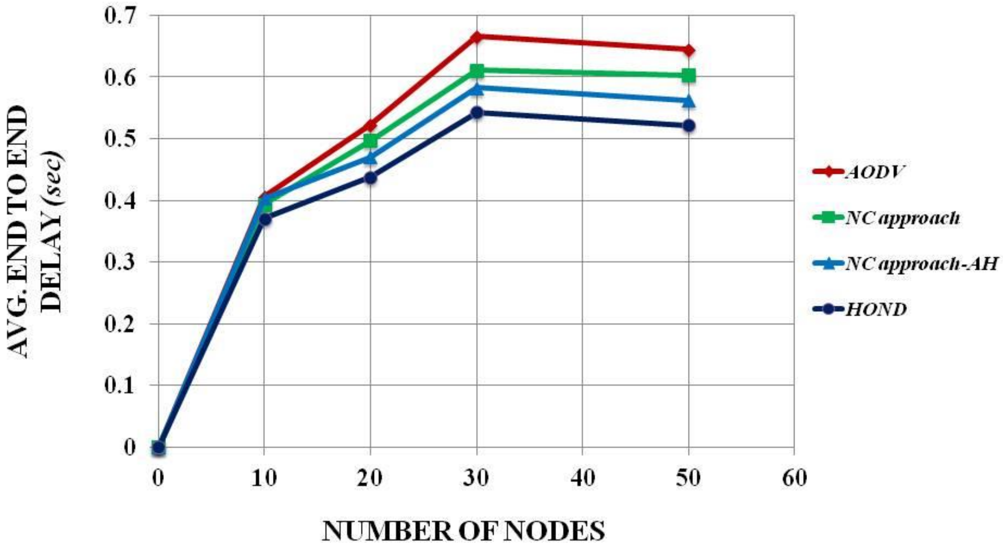

FIGURE 3: AVERAGE END TO END DELAY WITH VARIED NUMBER OF NODES

As from the fig. 3 we can see that all the approaches reduce the average end to end delay by an amount of 2-9 % as the number of nodes increase. Which is considered significant keeping in mind that the scope for reduction in delay is fixed. HOND is able to achieve that is because of quick dissemination of neighbor knowledge to the network, without adding computational complexity to it.

Packet Delivery Ratio: PDR is defined as the ratio of number of data packets successfully received by the CBR destination to the number of data packets transmitted by the CBR source. It is defined in per cent. It gives the throughput of the network.

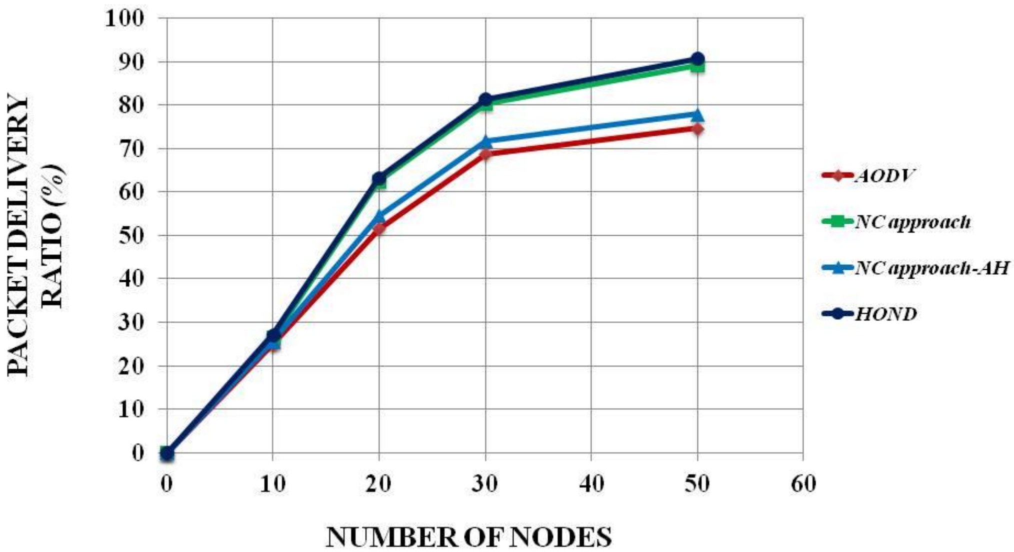

FIGURE 4: PACKET DELIVERY RATIO WITH VARIED NUMBER OF NODES

Fig. 4 shows the packet delivery ratio with varied number of nodes. It can be seen that NC approach increases the PDR by 16% but when clubbed with adaptive *HELLO* messaging, it reduces the PDR by almost the same amount. This means that inclusion of adaptive *HELLO* messaging scheme greatly reduces the routing overhead, but that comes at the cost of decrease in packet delivery ratio, which was expected because we compromised with the probability of detection of link failure in order to adaptively suppress the number of *HELLO* messages and overhead caused by the same. HOND multipath routing again reassures that PDR, by using alternate paths in case of link failure. So there is a need for consideration in applications where fidelity of data is major performance issue.

V. CONCLUSION

In this paper, we proposed a routing protocol to make efficient use of probability based mechanism and neighbor knowledge in combination with adaptively varying *HELLO* interval. For the reliability of communication, we used multipath routing protocol based on energy of the nodes. All the schemes and metrics are correlated such that they complement each other. Simulation results show that proposed protocol results in lesser rebroadcast traffic than flooding. Defining forwarding order of each node and using multipath routing results in mitigation of the network collision and contention, which translates into increased packet delivery ratio and less end to end delay. With significant reduction in routing overhead caused by the control packets and *HELLO* messaging and also the average end to end delay, routing performance of the proposed system gradually but significantly increases with addition of multiple schemes. When it comes to packet delivery ratio, the throughput alters a bit with each new addition, but they all perform better than the AODV routing protocol. Conclusively it can be said that proposed Hybrid On-demand Node Disjoint (HOND) multipath routing protocol provides significantly better routing performance overall than AODV.

REFERENCES

[1] D. Johnson, Y. Hu, and D. Maltz, "The Dynamic Source Routing Protocol for Mobile Ad-hoc Networks (DSR) for IPv4," RFC 4728, 2008.
[2] Charles E.Perkins, .Ad hoc Networking, Pearson Edition,2001 ch. 1.
[3] E. Belding-Royer and S. D. C. Perkins, “Ad hoc on-demand distance vector (AODV) routing,” July 2003.
[4] B. Williams and T. Camp, “Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks,” Proc. ACM MobiHoc’02, pp. 194-205, 2002.
[5] Tasneem Bano, Jyoti Singhai.2010. Probabilistic Broadcasting Protocol in AD HOC Network And Its Advancement: A Review.
[6] Seon Yeong Han, Dongman Lee, " An Adaptive Hello Messaging Scheme for Neighbor Discovery in On-Demand MANET Routing Protocols" IEEE COMMUNICATIONS LETTERS, VOL. 17, NO. 5, MAY 2013.
[7] X. Wu, H. R. Sadjadpour, and J. J. Garcia-Luna-Aceves, “Routing Overhead as A Function of Node Mobility: Modeling Framework and Implications on Proactive Routing,” Proc. of IEEE MASS’07, pp. 1-9, 2007.
[8] Xin Ming Zhang, En Bo Wang, Jing Jing Xia, and Dan Keun Sung, "A Neighbor Coverage based Probabilistic Rebroadcast for Reducing Routing Overhead in Mobile Ad hoc Networks" IEEE TRANSACTIONS ON MOBILE COMPUTING, VOL. 11, NO. XX, 2012.
[9] X.M. Zhang, E.B. Wang, J.J. Xia, and D. K. Sung, “An Estimated Distance based Routing Protocol for Mobile Ad hoc Networks,” IEEE Transactions on Vehicular Technology, vol.60,no.7, pp.3473-3484,Sept. 2011.
[10] Essam Natsheh, Adznan Jantan, Sabira Khatun, and Shamala Subramaniam "Adaptive Optimizing of Hello Messages in Wireless Ad-Hoc Networks" The International Arab Journal of Information Technology, Vol. 4, No. 3, July 2007 pp 191.
[11] Raphael Ernst, Peter Martini, " Adaptive HELLO for the Neighborhood Discovery Protocol " 37th Annual IEEE Conference on Local Computer Networks 2012.
[12] Manu J Pillai, M P Sebastian, S D Madhukumar " Dynamic Multipath Routing for MANETs – A QoS Adaptive Approach" IEEE TRANSECTIONS ON MOBILE COMPUTING 2013.
[13] Yun Ge, Guojun Wang, and Jie Wu, " Node-Disjoint Multipath Routing with Group Mobility in MANETs" Fifth IEEE International Conference on Networking, Architecture, and Storage, 2010.
[14] Feng Xue, P.R. Kumar. 2004. "The Number of Neighbors Needed for Connectivity of Wireless Networks".