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Density Based Routing Algorithm for Spare/Dense Topologies in Wireless Mobile Ad-Hoc Networks

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Abstract: Problem statement: A Mobile Ad-Hoc Networks (MANETs) operate in environments without infrastructures with an undefined network size. Most routing protocols of Mobile Ad-hoc Networks (MANETs) were studied using open space models where nodes were able to move throughput the entire simulation area. However, a more realistic topology should account for restricted mobility of nodes, such as in an urban city setting where there may be concentrations of nodes within specific areas (such as within buildings) and low density of nodes in other areas (such as in parks and roadways). Consequently, the simulation area should be partitioned into smaller sub-areas with varying densities to model such topologies, called spare/dense topologies. **Approach:** This study characterized the effect of spare/dense topologies on MANET routing performance and proposes an extension for an existing routing protocol to work in such topologies. **Results:** The proposed protocol improved the performance of MANETs by reducing the communication overhead incurred during the routing processes by implementing a new broadcast algorithm. The proposed broadcast algorithm was based on the density and connectivity of the nodes and not just the number of nodes. **Conclusion:** Compared with simple flooding, the proposed algorithm can improve the saved broadcast up to 50% without affecting reach ability, even under conditions of high mobility and density.

Key words: Ad-hoc networks, nodes density, broadcast management, routing protocols

INTRODUCTION

Mobile Ad hoc Networks (MANETs) are basically non-infrastructure based networks with an undefined network size. This is due to the ubiquitous nature of the MANETs that allows any device to be attached to a certain network anytime. It is only limited by range of the wireless transmission. Thus, there are many problems and issues that need to be addressed for MANETs protocols. One of the main issues is the nodes movement and the dynamic change that occurs in the network topology.

This study proposed on studying the operation of MANET in an environment with varying network node densities, called heterogeneous density environment. Previous studies on the impact of MANET node density have shown that MANET operation is very dependent on the availability of neighbor nodes. Studies by (Royer *et al*., 2001) have shown that MANET nodes would either have to move at moderate speeds or increase its transmission power in order not to be isolated from the network. Otherwise, a sparsely populated MANET environment would suffer a significant performance drop or would not be connected at all. Mobility for MANET nodes is one of the main problems identified when MANET routing is performed. Nodes with constant motion are expected to form temporary groups or sub-network within the original MANET. Thus, when these nodes travel at high speeds the topology of the MANET becomes even more inconsistent and consequently degrading its network performance.

Deploying MANET in urbanized areas with a mixture of vehicular and pedestrian traffic and disaster areas would fit into the scenario where node densities vary from time to time. The main contributing factor would be node mobility creating small non-uniform networks within the same network area.

To overcome the above problem, the routing protocol broadcast the routing information via the network. That consequently issues a problem known as "broadcast storm" (Ni *et al*., 1999; Tseng *et al*., 2003; Zhang and Agrawal, 2005). This event occurs when a high number of broadcast activities are performed simultaneously at a certain period of time and triggering torrents of redundant broadcasts requests and replies

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that will eventually lead the contention based link layer of MANETs to suffer a blackout (Ni *et al*., 1999). In networks with varying node densities, such problems is expected to occur more frequently as MANET nodes will be forced to reiterate its broadcasting events whenever there is a broken link or when the destination could not be found over a certain period of time. The performance of the communication in the network will then eventually decline over time (Siddique *et al*., 2007).

In short, the problems identified in this study on MANETs with varying node densities are: Low packet delivery, low throughput, high end to end delay and potential "broadcast storm" problems due to unmanaged network broadcasting soliciting very high number of routing overheads in highly dense areas of the network.

The proposition to solve the problems discussed earlier will be a density based probabilistic algorithm to be implemented on MANET routing protocols. The proposed algorithm will be neighbor aware and is expected to perform broadcast at rate which is determined by the density of the network. The algorithm is expected to collect neighbor information based on an incremental counter for every route update that is performed prior to performing the Route Discovery process. Thus, the algorithm is expected to perform less frequent broadcasting activities when there are a high number of neighbors around and will assume normal broadcasting activities when the amount of neighbors are low. The objective of the algorithm is to lower the amount of routing packets per data packet as to increase the efficiency of the network. It also limits the number of broadcast reiterations performed based on the density of the nodes in the same area. The number of broadcast iterations in the current implementation is not adjusted according to the topology of the network. The situation increases the possibility of soliciting a torrent of route replies from other nodes receiving the broadcast. The replies would then contribute to the "broadcast storm" problem. While reducing the number of broadcast iterations according to the density of the network will help dense networks to reduce the amount of packet collisions that may occur due to a "broadcast storm". On the other hand, sparse networks would continue to perform its broadcasting activities similar to the current implementations.

Nodes density issue: The optimum density of MANETs was studied in (Royer *et al*., 2001), which discussed the tradeoffs between network density and node connectivity in the face of increasing node mobility and proposed an optimal node density for maintaining connectivity in a stationary network. However, the results were inconclusive regarding the optimal density for maintaining connectivity in highly mobile environments. When neighbor nodes are saturated they yield almost similar results. For instance the number of nodes converge around 3 and the throughput converged around less than 0.1. Nonetheless, (Royer *et al*., 2001) concluded that both transmission power and the node densities need to increase when nodes experience increasing mobility if connectivity were to be maintained.

In real life situations large mobile networks will not have uniform sets of nodes populating the network area. Instead, groups of nodes varying in numbers would be found scattered around the network area. This situation can be reflected in the normal urban mobile network environment setup or other scenarios such as disaster areas and vehicular networks. Therefore to evaluate the performance of MANETs in an environment without considering the situations mentioned earlier could not provide a clear picture on the scalability of the MANETs routing protocols.

Network node density for an entire network can be differentiated into physical density versus connectivity density. In this study network physical density is defined as dense when large number nodes are in proximity of one another within a particular area and vice versa for sparse. However, when determining density for a particular network, one should also consider the connectivity of the network in terms of transmission range that covers the particular area. Thus the network density determined in this study, is based on the number of nodes found in a particular area and the connectivity of the nodes. Therefore even though the number of nodes found in a small area may not be packed, given a high transmission range then it can be determined that the node in the area is dense. Otherwise given either a very large or low connectivity the node density could be determined as sparse.

On the issue of connectivity density, studies by (Bettstetter and Zangl, 2002; Bettstetter, 2002) discussed determining the network connectivity based on the density of the numbers of neighboring nodes. The density is defined based on the transmission range of the nodes. The definition of connectivity density of a network based upon the study is as follow:

- The number of neighbors surrounding a node is denoted by its degree d
- A node that has a degree $d = 0$ is said to be isolated from the rest of the network

- The minimum degree of nodes d_{min} and is considered as the smallest degree of all nodes in the network
- A network is said to be connected when every pair of nodes exists a path between them, otherwise it is disconnected
- A connected network always has a minimum degree $d_{min}>0$ but the reverse implication is not necessarily true
- A network is k-connected if for each pair of node exists k mutually independent paths connecting them

P is the probability of the connectivity. The value n is the number of nodes located in the area. The value μ is represented by Eq. 2 where ρ is the density, π represents the circumference and r is the radius of the transmission:

$$P(k\text{-con}) \approx (1-e^{-\mu})^n \quad (1)$$

$$\mu = \rho \times \pi \times r_0^2 \quad (2)$$

$$\rho = n/A \quad (3)$$

Based on this one can have the criteria for determining the size of each 'square' in the topology. In this study the value of k is set to1. This means that in any particular network mentioned as dense given the probability of the connection of $P(k\text{-con}) \geq 0.95$ where k = 1, there is 1 mutually independent path connecting the nodes in the particular network area. Thus the network is categorized as (almost surely) 1-connected. This also implies that for any neighbors found within the transmission range of a particular node they are at most 2 hops away from each other. The node density of the network areas in this study will be based on the formulae provided for P(k-con). Therefore an area is considered dense when a MANET source node identifies that:

- It neighbors are at most 2 hops away from it and it has a mutually exclusive path to other neighboring nodes that is independent of one another $P(1\text{-con}) \geq 0.95$

Sparse areas will be areas where nodes are isolated from a network or from one another:

- Nodes in a sparse neighbor cannot guarantee at least a single connection in the network $(P(1\text{-con}) \leq 0.95)$
- The minimal neighbor node degree for sparse areas could be $d_{min} = 0$. Thus, the node could be disconnected from the network

To alleviate certain known problems in MANETs many alterations to the original routing protocols have been introduced. Some required small and some required an overhaul of the original algorithms. In many cases MANETs routing protocols alterations relates to the applications in which it is intended for. There are also intentions to adopt MANET technology in vehicular networks and some in sensor networks as well. Whatever the intention the MANETs is design for some common or basic problems still remains in the available protocols when it is moved to into real implementations.

MATERIALS AND METHODS

In the following, the proposed concept and procedure for density based probabilistic algorithm that is used with AODV routing protocol will be introduced.

Density based probabilistic algorithm for AODV (AODV-P): The number of neighbors used for deriving the neighbor size will be based on the neighbor cache that is utilized by the ad hoc routing protocol. In general the density calculation determines how the RREQ sending and forwarding process will take place (Fig. 1).

Previous comparisons of MANET protocols observed that on-demand MANET routing protocols (Abolhasan *et al*., 2004) perform relatively better that table driven or proactive routing protocols in terms of incurring overheads and freshness of routing information in highly dynamic MANETs. Thus, Ad-hoc On-demand Distance Vector (AODV) routing protocol (Perkins *et al*., 2003) was chosen to be incorporated with the density based probabilistic algorithm and called AODV-P.

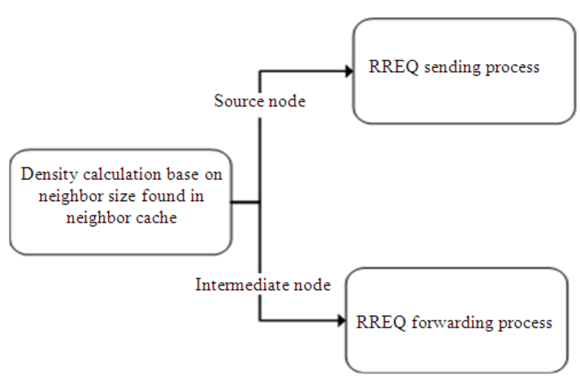

Fig. 1: Simplified block diagram for AODV-P on when to forward or initiate RREQ

The AODV-P modifies the Route Request sending and forwarding. These are the two phases in AODV routing that performs the most broadcasting activity during its Route Discovery period. During the Route Discovery period, route solicitation ignites a high number of broadcast activities if the topology of the network is dynamic. Thus the algorithm will provide a certain control of how far the broadcast message will go in terms of the number of hops.

In situations where network density varies, node mobility is the main factor for transmission instability. Mobility in sparse areas leaves the communication in the entire network at the mercy of certain individual nodes. High link loss in MANET due to mobility will bear the following consequences in networks with varying densities:

- Nodes in dense areas will flood the network with RREQ packets to reinitiate the data transmission
- High packet loss occurred due to 'Broadcast storm' for nodes in the dense network
- Routing packets would consume the bandwidth usage rather than data transmission

Message transmitted from a dense portion of a network to another dense network via a sparse area will cause the AODV protocol to behave erratically. It is only when chanced upon certain speed that some of the nodes maybe placed in a better position than others. While the position of the nodes is not guaranteed, the routing overheads due to broadcast activity keep increasing at dramatic rate. The implementation of density based probabilistic algorithm is expected to reduce the range and delay the forwarding of the RREQ packets sent or forwarded during route discovery in such environments. The rationale for such purpose is as follow:

- Given that in a dense area a neighbor node is 1 or 2 hops away, if a route is not discovered then it is not necessary to flood the entire network with RREQ messages
- Dense area nodes that communicate through sparse areas will experience a high number of MAC collisions during link breakages due to simultaneous flooding
- In dense areas aggressive packet forwarding is not recommended as packet collision is highly probable and a delay on top of the CSMA/CA back off would help to reduce collision of packets
- Nodes in sparse areas should drop packets faster when the route is down

```
Upon initiating a Route Discovery when RREQ packet is
sent
        Access Neighbor Cache
        If Neighbor not equal to null
                NC++;     //NC: neighbor count
                Return NC;
        End-if
        If RREQ_Count = 1
                Broadcast packet with TTL_START;
        Else
           If DENSITY (calculated with NC)< 0.95
                If TTL < THRESHOLD (7 hops)
                    HC=HC+2; //HC: hop count
                Else
                    TTL=THRESHOLD + HC;
                        If TTL > 30 hops
                            TTL = 30 hops;
                        End-if
                End-if
          Else
           Broadcast with NETWORK DIAMETER
                (simple flooding 30 hops)
          End-if
   End-if

Fixed Parameters:
TTL_START = 5 hops;
THRESHOLD = 7 hops;
```

Fig. 2: Proposed AODV's route discovery sending algorithm

Density calculation: The density is calculated based on Eq. 1-3.

Neighbor count is collected: Calculate density with:

$$\rho = n/A$$

n = Neighbor count
A = Pre-defined area size

Calculate μ:

$$\mu = \rho \times \pi \times r_0^2$$

ρ = density
π = 3.142
r_0^2 = The transmission radius

$$P(k\text{ -con}) \approx (1\text{-e-}\mu)n$$

is calculate to determine the connectivity probability.

Route discovery sending phase: We suggest changing AODV's route discovery sending algorithm to be as shown in Fig. 2.

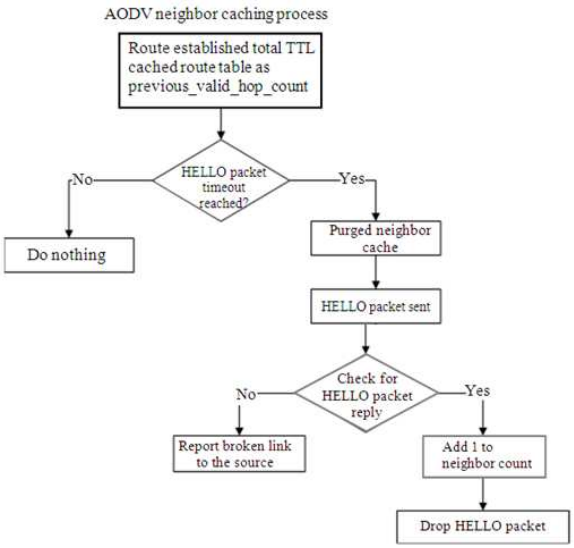

Fig. 3: Neighbor count acquisition mechanism for AODV-P

As illustrated on Fig. 3 the neighbor nodes will be decided by those that had recently replied the source node with a HELLO packet. The reply from the HELLO packet will be added into the cache until the next timeout occurs. The reply from each unique HELLO packet will be taken into account as neighboring nodes to determine the density. The number of the neighbors will change according to the mobility of the network thus for each neighbor cache purged the number of neighbors will reset and the process continues until the AODV-P protocol stops.

The proposed algorithm will mostly depend on the density of the neighboring nodes to decide it next course of actions unlike the original AODV protocol. This aids the nodes in sparse areas to increase their ability to reach further when sending the RREQ message. The nodes in the dense areas will only extend its reach based on the THRESHOLD + HC to the destination after successive retries which the TTL is below 7. This is different from the original AODV where the entire network will be flooded at this point.

The flowchart in Fig. 4 shows how the extension for AODV-P differs from the original AODV by extending an extra condition to determine if the network diameter has been reached. The original version of the AODV is much simpler while the AODV-P will improvise from the existing expanding ring search. Based on the conditions applied in AODV-P the Route Discovery may not even reach the network diameter even when the Route Request cycle runs out. For example when the packet is traversing in from dense to sparse areas of the network the amount of RREP packets generated could be much less due to less number of RREQ being generated in the first place.

The important messages involved in the Route Discovery process are the Route Request (RREQ), Route Reply (RREP), Route Error and HELLO messages. The RREQ, RREP and RERR are used only during the preliminary discovery while the HELLO message is used as more of a maintenance purpose. Furthermore, these messages will be calculated later as part of the packet overheads later on in the metrics calculation aside from the HELLO messages.

This is to reduce the number of hops traversed by the broadcast packet and stop flooding of the entire network blindly. Broadcast actions taken in the RREQ sending phase will consequently affect the rest of the route discovery having implications on packet delivery and average delay. But the parameter most affected by this course of action will be the amount of routing overhead incurred which is expected to be lowered significantly.

Route discovery forwarding phase: The AODV-P Route Discovery forwarding algorithm is as follow:

```
Upon initiating a Route Discovery when RREQ packet is sent
    Access Neighbor Cache
    If Neighbor not equal to null
        Increase neighbor count.
        Return neighbor count
    End-if
    If DENSITY (calculated with NC) < 0.95
    Forward the packet with a random delay
    Else
       Forward the packet without any delay
    End-if
```

RREQ forwarding based on the algorithm would be sent faster in sparse network and very slow in dense networks. This is basically to allow nodes in sparse networks to send faster and drop the packets in queue faster to avoid sending stale packets. However in dense networks, since the connectivity is guaranteed a high delay would be a precaution against a broadcast storm.

The delay incurred during the packet forwarding in the AODV-P is to slow down the propagation in dense networks. If the network is dense a random amount of delay is introduced (in the case of this experiment the random delay is around 10 m sec). In sparse networks no delay is introduced and the packet is forwarded as soon as the node identifies that the packet is not destined for it. The contrast in the forwarding policies are based on the needs that arises from the two types of extreme environments. The code flow is depicted in Fig. 5 and 6 for AODV and AODV-P respectively.

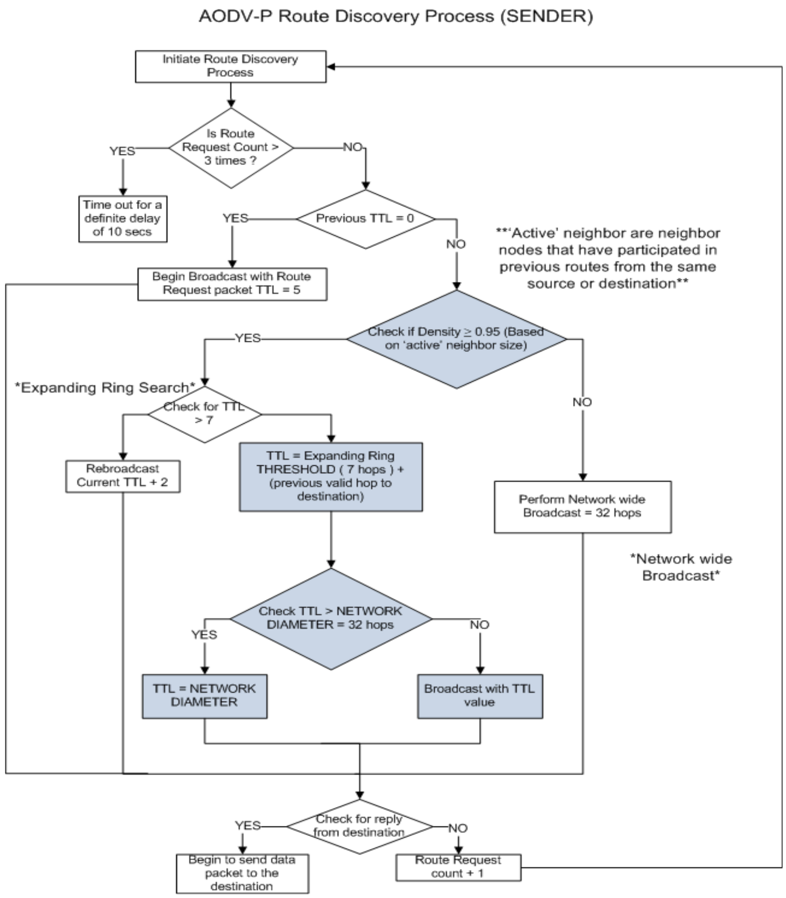

Fig. 4: RREQ packets sending mechanism for extended AODV protocol

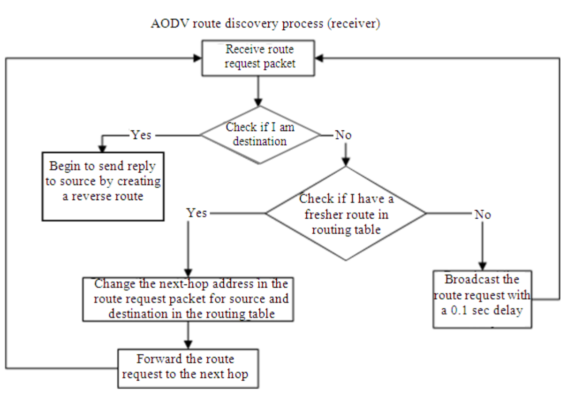

Fig. 5: Forwarding mechanisms for RREQ packets in original AODV protocol

The overall contribution of proposed in this study focuses on the Route Discovery phase, during the initiation of the Route Discovery and the forwarding phase. The neighboring node size is updated according to the periodic updates from the Route Maintenance phase that has taken place previously. This is to provide leverage for transmission source nodes that had routes established earlier and had recently lost its route. The neighbor size is expected to change from time to time for each individual node in the MANET due to the mobile nature of the network. Hence, even when there are nodes that appear to be in proximity to the source node, if it was not participating in any transmission previously it will be discounted from as a neighbor. Therefore the neighboring nodes that are taken into account in this study would be better addressed as 'active neighbors'. The characteristics of active neighbors are as follow:

* Participated in previous routes for source nodes in the same network
* Performed Route Discovery of its own
* Not dormant and has updated the source of its existence during Route Maintenance

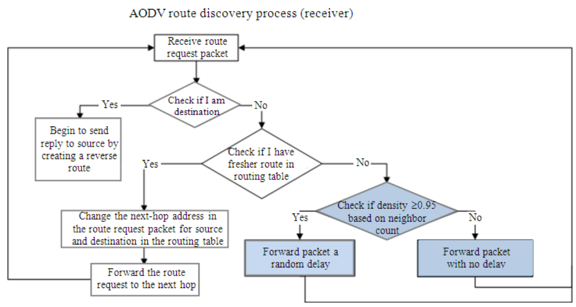

Fig. 6: Forwarding mechanisms for RREQ packets in extended AODV protocol

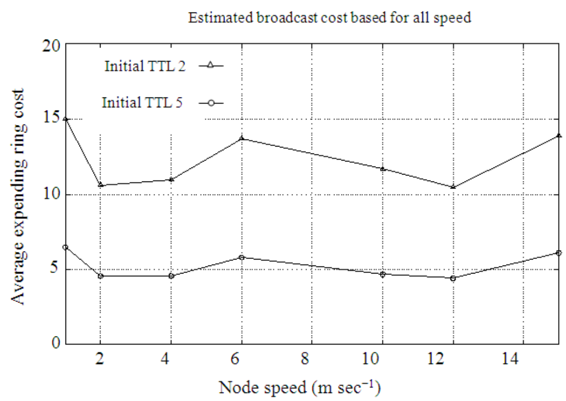

Fig. 7: Forwarding mechanisms for RREQ packets in extended AODV protocol

During the initial discovery of routes by any nodes in the MANET, most nodes will be oblivious towards each other's existence until some of them begin to participate in data transmission. Thus the probabilistic algorithm proposed in this study aims to reduce the impact of routing overheads over time. The value of previously known hop count to the destination applies only when there was a route previously established before the route discovery. If the addition of the hop count with the threshold hop count surpasses the network diameter the value would fall back to the network diameter.

Certain values used redefined for AODV-P configuration is based on the topology proposed in the study conducted in this study. The value like the initial TTL which was by default 2 was changed to 5. This is due to the broadcast cost that is estimated in the topology with varying density. The value of the threshold for the Expanding Ring search TTL remains similar to the default value which is 7 as proposed by RFC 3561. This is to limit the amount of Route Discovery phase to no more than 3 cycles of broadcast. The broadcast cost that is involved for selecting the initial TTL value of 5 and 2 is showed in the Fig. 7. The graph showed a more efficient coverage for the TTL value of 5 compared to 2 as more cycles of broadcasts are expected in the proposed topology. The broadcast cost is calculated based on the study presented by (Royer *et al*., 2001) which uses the equation:

$$B_k = 1 + \sum_{i=1}^{k-1} n_i \qquad (4)$$

The variables in equation 4 are defined as follow:

B_k = Broadcast cost
k = Number of hops taken
i = Initial hop count
n = Number of nodes which translates to the overall broadcast cost

Thus the total nodes found in the broadcast ring of each hop equals to the broadcast.

In sparse areas of the MANET flooding will be frequent and route forwarding would not have any delays as to increase the speed for routing information to be updated. Frequent flooding in sparse areas would not consume as much bandwidth as dense networks as there are fewer nodes performing the similar action. Fast forwarding will allow RREQ packets that have a low probability of a neighboring node to exhaust its TTL faster in order not to leave the packet to drift around network for too long. Such efforts are aimed to help nodes in sparse areas with a better chance of looking for its destination during the Route Discovery phase.

RESULTS AND DISCUSSION

The proposed algorithm is expected to provide leverage for the AODV route discovery phase and is expected to improve certain issues such as:

- Reduced possibility of the occurrence of a 'broadcast storm' during communication through sparse areas
- Reduce the number of hop counts required to traverse through the sparse area
- Broken links in the sparse areas are reported faster as there are no delay imposed on the forwarding of routing packets

The expected outcome would reduce the number of routing overheads compared to the original AODV.

Better packet delivery ratio is expected and a slight improvement in terms of throughput. The delay for AODV-P may be much higher than the original AODV due to the imposed delay of forwarding packet in dense networks. Thus reasonable improvement to the original AODV protocol can achieved in environments with varying densities.

CONCLUSION

This study has weighed up the performance of density based probabilistic algorithm on the AODV protocol, which traditionally uses simple flooding, in order to increase saved rebroadcasts of route requests at route discovery sending phase and route discovery forwarding phase. This proposed algorithm determines the rebroadcast probability by taking into account the network density. In order to improve the saved rebroadcasts, the rebroadcast probability of low density nodes is increased while that of high density nodes is decreased. Compared with simple flooding, we expect that the density based probabilistic algorithm can improve the saved broadcast up to 50% without affecting reach ability, even under conditions of high mobility and density.

As a prospect for future work, we plan to evaluate the performance of proposed density based probabilistic algorithm on the DSR algorithm. Then we aim to build an analytic model for our approach in order to facilitate the exploration of the optimal adaptation strategy, with regard to probability setting and network density. Finally, since the technique avails itself to various types of network-wide dissemination, we plan to integrate it with a proactive routing protocol, namely OLSR. This protocol already incorporates techniques which reduce the effect of flooding and are orthogonal to our scheme, which implies the opportunity to examine if cumulative improvements with our method are possible.

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