Effects of Applying Mobility Localization on Source Routing Algorithms for Mobile Ad Hoc Network.

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Abstract

Network topology in Mobile Ad Hoc Networks is subject to constant/abrupt change. Source routing algorithms tend not to perform well due to this unstable topology, which invalidates the source routes often, however, the changes in the topology are often local due to the continuous nature of physical movement of nodes. The hypothesis behind this work is that performance of source routing algorithm can be enhanced by localizing these changes in the source route due to mobility, called "Mobility Localization". Rest of the work discusses and evaluates this hypothesis.

1. Introduction

Routing problem in the Mobile Ad Hoc Networks (MANETs) has attracted a lot of attention among researchers over the past few years. A number of solutions to this problem are proposed. [1,3,4,6,7,8,9]. Broch et. al. present a nice comparison of some of these routing algorithms in [2]. Concept of source routing, well understood in the realm of fixed networks, has also been applied to this domain by Johnson et. al. [5].

Source routing is a problem of finding and maintaining a complete, ordered list of nodes (source route) through which the packet should pass to reach the destination. The source route can be thought of as a acyclic sub-graph of network topology graph. The idea behind all source routing solutions is to allow a source node to dynamically discover a route across many hops to any destination in the network. This discovery is done before any data packet can be send to the destination and again when the source route is invalid. This cost of discovery is the only overhead imposed by the source routing algorithms. This overhead can be significant due to the unstable topology of MANETs, which frequently invalidates the source route.

Mobility localization can help minimizing this route discovery overhead. The fundamental principle behind mobility localization is that even if a mobile node has moved at a time t, there is a fair possibility that it might be found in the neighborhood until time $t+\delta t$. Here the value of δt depends on the velocity vector V of the mobile node and the definition of neighborhood at that instant. Attempting to find the node in the vicinity instead of starting the route discovery procedure again can minimize the overhead due to source routing. This will localize the effect of mobility of the mobile node, preventing the nodes far away from it from spending precious bandwidth on the route discovery and route maintenance procedures thus decreasing the overhead to data transmitted ratio further.

In a mobile network, the propagation of the information that a node has moved can create lots of overhead traffic. It can cause lots of route maintenance code to execute. The primary objective of the proposed solution is to decrease the overall communication overhead of source routing without resorting to active information exchange, such as exchange of hello packets. The source node decides about the perfect balance between the cost of routing information propagation and the staleness of routing information. In order to explain to the reader why this tradeoff can be a valid concern in routing in MANETs we are displaying it through an example in section 3.

The rest of this paper is organized into five sections. Section 2 discusses some related work in the area. Section 3 describes the modification proposed to include localization of mobility in the source routing solutions. Section 4 explains the approach with the help of an example, which compares the source routing algorithm with and without localizing the mobility. Section 5 describes the evaluation procedure of the new approach. Section 6 describes and discusses the results and section 7 concludes.

2. Related Work

Earlier work done in reducing the routing overhead loosely falls into two types. First, to reduce the routing overhead by decreasing the number of nodes receiving route queries, and second, decreasing the number of route requests generated by the source node. Location Aided

Routing [14] and Query Localization Techniques [13] are the prominent among the first category. Dynamic Source Routing [5] and Neighborhood Aware Source Routing [11] fall into the second category.

To reduce the overhead of source routing Dynamic Source Routing [5] applies packet salvaging. The approach works as follows: On detecting failure of a next hop transmission an intermediate node tries to find alternate routes in its route cache to reach the destination. If the node has an alternate route to the destination in its Route Cache, it replaces the original source route on the packet with the route from its Route Cache. It then forwards the packet to the next node indicated along this source route. This approach relies on the possibility that an alternate source route from the intermediate node to the destination is present in the route cache. This may not always be true. There is also a fair possibility that the event (change in position of the node, node going down etc.), which invalidated the primary route, will result in an invalidation of the alternate route as well.

Neighborhood Aware Source Routing [11] actively maintains a partial topology of the network by transmitting hello packets, thus incurring routing overhead even when there is no data exchange.

Location Aided Routing [14] restricts the flooding of the query using Global Positioning System. The approach mentioned in [13] utilizes the same basic principle as the approach proposed herein. As far as the authors understand, however it requires the source node to respond to the route error by sending a route request again, and all nodes flood the route request depending on the predefined flooding heuristic.

3. Source routing with mobility localization

Source routing in general consists of two parts, route discovery and route maintenance. The use of mobility localization will not affect the route discovery. Modification of route maintenance procedure is, however, necessary to take care of the requested localization of the errors in a source route. Localization of mobility is used as a best effort service: i.e., a node will take care of the requested localization of mobility, only if it is possible for it to do so.

There can be many ways to convey the localization information to the nodes at the farther end of the source route. A new field can be associated with every source route representing the localization value. Maintenance of a globally known or negotiated localization value across the network is also possible. The third approach can be to compute the localization value as and when it is needed using information like source route length, mobility of the destination node, etc. In the first case, before sending a packet the source node updates the localization field along with other fields in the packet. In the second case, before sending the first data packet, sending a special packet is necessary to intimate every node on the source route of the requested localization value. In the first two approaches, the source node devises a value of localization and in the last approach; nodes near the destination do it when there is a route error.

When the data link layer of a node reports a transmission error in forwarding a packet to the next hop in the source route, the route maintenance procedure of a source routing algorithm generates a route error. This route error is sent directly to the source node. In this proposal, before sending a route error to the source node, the node encountering error in forwarding the packet analyzes the source route, localization value for the source route and its position in the source route. If the node is within α hops from the node encountering next hop error, where α is the value of localization, before sending a route error to the source node the node tries to repair the source route on its own. If it is successful in repairing the route, it forwards the traffic for the destination using the new route. If it fails to repair the route, it checks the value of localization again to see whether any other node just before itself in the source route is eligible to repair the route: i.e., whether that node is within α hops from the node encountering next hop error. If yes, it sends a route error to that node. The node m is considered for forwarding route error before node n in the source route if m is before n in the ordered sequence of nodes from source to destination. The node m is considered just before node n, if m is before n in the source route and m and n are neighbors.

A node can receive a route error only if it is within α hops to a node encountering next hop error in a source route or it is a source node of the source route. In the first case, the node starts the route repair procedure, whereas in the second case it starts the route request procedure. A route repair procedure works as follows. A node receiving the route error sends a route repair message to every other one-hop neighbor known to it, except the node from which it has received the route error message and the node just before itself in the source route.

The route repair message is sent as a point-to-point unicast message and it contains the id of the node that is being searched. A node does not broadcast the route repair message until and unless it has no nodes to forward this message. The hop count of the route repair message is decremented each time it is forwarded and the message is discarded once the hop count reaches 0. A node on receiving a route repair messages checks to see whether the node requested in the message is known to it. If yes, it sends back a route repair reply to the originating node. If no, it checks whether it can forward the route repair message; if it can forward it, forwards the message to every node except the one from which it received the message.

Every node starts a timer after sending a route repair message. The value of the timer is proportional to the hop count of the route repair message. When the route repair timer times out at a node it no longer forwards the route repair reply messages to the sender of the route repair message.

Localization value should be proportional to the source route length. As we will see in the experiments section, increasing the Localization value until a threshold Γ in an average path length L does decreases the overhead, but there is no significant benefit achieved if we increase the localization further beyond Γ. Let us theoretically compare the overhead involved in route maintenance using mobility localization and overhead involved in basic source route maintenance. Assuming the source route length to be L, average degree of a node in the network to be d, and the number of hops a route repair request be forwarded be h, the worst case overhead will be when the node initiating route repair will need to explore its entire sub-tree to be able to find the destination node. Let p be the probability that the destination node can be found in the sub-tree of the node repairing the route, C be the overhead of a route repair message, C_{src} be the overhead of the route maintenance using source routing and $N(d,h)$ denotes the number of nodes in d-ary tree of depth h. The worst-case overhead of localizing an error with a localization value 1 can be given as:

$$p.(d-2).N(d-1,h).C$$
$$+(1-p).((d-2).N(d-1,h).C+C_{src})$$

The overhead of source routing is $C_{src,}$ so the net advantage of this approach over source routing is:

$$p.C_{source}-((d-2).N(d-1,h).C)$$

As can be observed the overhead minimization achieved by this approach depends on the probability that the missing destination node is found later in the sub-tree of the node repairing the route.

4. Mobility localization

Imagine a network of 10 nodes as shown in the figure 1-5. The Fig. 1 shows the initial condition in the network in which the circles represent nodes and there is a dotted line between two nodes if they are in the radio range of the other to use it to communicate to the rest of the network. An underlying assumption throughout the discussion is node 7 is sending messages to node 10 using the source route {7,6,5,4,8,10}. Another assumption for simplifying the explanation is the relatively static nature of every node except node 10. Node 10 moves around in such a way that it is in the radio range of node 8, node 9, node 3, node 2, and node 5 at time t0, t1, t2, t3, and t4 depicted in Figure 1, 2, 3, 4, and 5 respectively. The dashed ellipse around the node represents the ideal localization of effects of the mobility of node 10.

In Fig. 2 node 10, moves near node 9 and uses node 9 to communicate, but node 4 can still reach it through node 8, so ideally any node including 4 and beyond should not know about the movement of node 10. In Fig 3 node 10 moves near node 3. Now all nodes beyond and including node 5 should not know about the movement. According to them node 10 can still be reached through node 4. Similarly in Fig 4, node 10 further moves near node 2. In this case this information should not be propagated beyond node 3, since for all nodes beyond node 3, they can still reach node 10 using node 3.

To see how it helps in hiding the latest information about movement from the rest of the network we will discuss a sample route discovery and maintenance phenomenon in the situation shown in Fig 1-5. We will first show how a typical source routing algorithm will work and then we will show the working of the mobility localization algorithm.

At t=t0 there exists a source route {7,6,5,4,8,10} between 7 and 10. At t=t1 node 10 is no longer reachable from node 8, so it sends a route error message to node 7. Node 7 upon receiving the route error starts the route discovery procedure again, which results in route request broadcasts by almost all the nodes of this network. Finally a source route {7,6,5,4,8,9,10} is established between node 7 and 10. At t=t2 again this source route is invalid, because node 10 is not reachable from node 9. As in previous case node 7 starts the route discovery again and almost all the nodes broadcast again. Almost same steps will be repeated at t=t3 and t=t4.

In case of localization based algorithm we assume that each node sends a variable "localization" along with every source route in a packet. The variable localization expresses how much the source node wants to avoid the routing error. We will use the notation localization(m,n) to denote the value of the localization variable for a source route from node n to node m. This variable signifies up to which level does node m want the forwarding node to avoid forwarding route error messages encountered in any traffic heading to node n. Value of localization α = localization(m,n) means that the intermediate nodes within α hops to the node encountering routing error should try to repair the source route between m and n. If it is not possible to repair the source route within α hops the nodes should give up and notify the source node of the route failure.

At t=t0 (Fig. 1) the source route that is being used is {7,6,5,4,8,10} and the value for localization(7,10) is 3. In this case, source node 7 instructs the forwarding nodes to start route repair if they are within 3 nodes from the node encountering route error, e.g. if the node 8 fails to forward a packet to node 10 the nodes 4 and 8 are expected to find an alternate route. At t=t1 (Fig2.) node 10 is no longer reachable from node 8, it then checks the value of localization(7,10) which is 3. So the node starts the route repair for the source route {7,6,5,4,8,10} by sending a route request message to all the nodes known to it except 4.

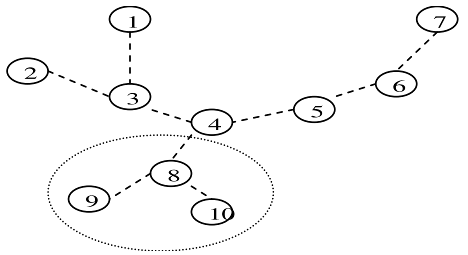

Figure 1. Initial condition (t=t0)

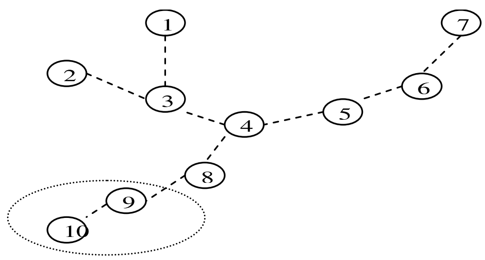

Figure 2. Node 10 moves in the range of 9. (t=t1)

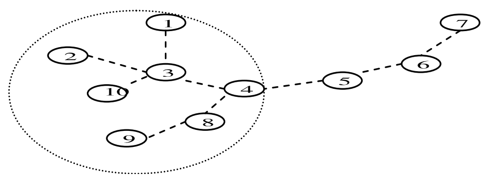

Figure 3. Node 10 moves in the range of 3. (t=t2)

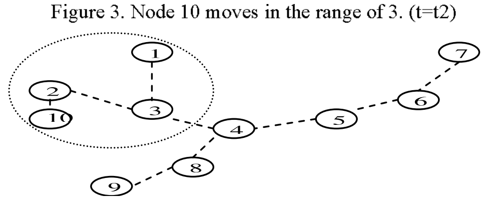

Figure 4. Node 10 moves in the range of node 2.

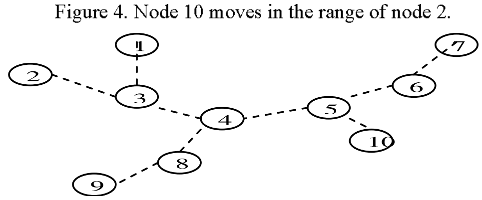

Figure 5. Node 10 moves in the range of node 5.

In this case, the only node known to it other than 4 is 9. Upon receiving the route discovery message node 9 tries to send the route request to all the nodes known to it except 8. There are no nodes other than 8 known to it, so it broadcasts the route request. Node 10 hears this message and sends a route reply to the node 9, which then forwards it to node 8. Node 8 then uses the new source route to forward packets to node 10. This new source route is unknown to any node beyond node 8, thus localizing the effect of mobility of node 10 to the minimal sub set of the network. At t=t2 (Fig. 3) again this source route is invalid, because node 10 is not reachable from node 9. Node 9 then checks the value of localization(7,10) which is 3. Therefore, the node starts the route repair for the source route {7,6,5,4,8,9,10} by sending a route request message to all the nodes known to it except node 8. There are no nodes other than node 8 known to it and it knows that it has generated a route error for node 10, so it checks the value of localization(7,10).

The value is 3: i.e. node 8 can still try to repair the route, so it sends a route error message to the next node 8 instead of sending a route error message to node 7. Node 8 on receiving a route error tries to repair by sending a route request to all the known nodes other than node 9 and node 4. There are no other nodes known to it so it broadcasts the route request. After it fails to receive any route replies it checks the value of localization(7,10), which is 3. The value is 3: i.e. node 4 can still try to repair the route, so it sends a route error message to 4 instead of sending it to 7. Node 4 starts the repair procedure by sending a route request to all the nodes other than 8 and 5. On receiving a route request node 3 forwards it to node 1 and 2. Nodes 1 and 2 in turn broadcast the route request. When the route request times out, node 3 broadcasts the request, which is heard by node 10. Node 10 sends back a route reply to node 3 and node 3 forwards this request to node 4. Node 4 on receiving the route reply mends the source route. In this case, nodes beyond node 4 were not aware of the mobility of node 10.

At t=t3 (Fig. 4) the node 10 moves again and the source route is invalid again. Node 3 then checks the value of localization(7,10), which is 3. Therefore, it starts the route repair for the source route, by sending a route request for 10 to all the nodes known to it except node 4. In this case, the only node known to it other than node 4 are node 1 and 2. On receiving the route discovery message node 1 and 2 try to send the route request to all the nodes known to them except 3. There are no nodes other than node 3 known to them so they broadcast the route request. Node 10 hears this broadcast message by node 2 and sends a route reply to node 3, which then forwards it to node 4. Node 3 then uses the new source route to forward packets to node 10. This new source route is unknown to any node beyond 3 thus localizing the effect of mobility of node 10 to the minimal sub set of the network.

Now suppose as shown in (Fig. 5) instead of moving towards 9 node 10 would have moved towards node 5 and at t=t1' was close enough to be in the radio range of node 5. Node 10 is no longer reachable from node 8, so it then checks the value of localization(7,10) which is 3. Therefore, the node starts the route repair for the source route {7,6,5,4,8,10} by sending a route request message to all the nodes known to it except 4. In this case, the only node known to it other than node 4 is node 9. On receiving the route discovery message node 9 tries to send the route request to all the nodes known to it except node 8. There are no nodes other than node 8 known to it so it broadcasts the route request. After it fails to receive any route replies it checks the value of localization(7,10), which is 3. The value is 3 so it sends a route error message to 4 instead of sending it to 7. Node 4 starts the repair procedure by sending a route request to all the nodes other than 8 and 5. On receiving a route request node 3 forwards it to node 1 and 2. Node 1 and 2 in turn broadcast the route request. When the route request times out, node 3 broadcasts the request. After the route request of 4 times out node 4 checks the localization(7,10) which is 3. So it sends a route error to the source node 7.

5. Evaluation of the approach

Evaluation of the approach is done using simulation of source routing and source routing with arrangements for mobility localization in parallel on the same network configuration and conditions. The basic source routing was assumed in all the cases. The optimizations proposed in [5] Route caching, snooping on source route, route shortening and route salvaging are already implemented in the simulation framework ns [15]. It helped us see the effectiveness of mobility localization on top of all the optimizations. A random waypoint mobility model is used. It is also assumed that at any point of time, all pair communication going on between node pairs in the network with a constant bit rate of 1Mbps. Random movement of nodes was used.

The maintenance cost in terms of number control packets exchanged for restoring the network back to stable state was calculated using source routing and source routing with mobility localization. The experiment was done with 10, 11, 12, 13, 14, 15 16, 17, 18, 19, 20 and 25-node network. The value of localization was varied from 1-3. The results are presented in the next section.

6. Results

The results are shown in a logarithmic scale on the vertical-axis and decimal scale on the horizontal-axis. Fig 6. shows the plot of number of nodes Vs. the route maintenance overhead in basic source routing and source routing with localization value 1, 2 and 3. The effect of applying localization can be observed. As the value of localization is increased the overhead reduces further.

We can see the significant difference between overhead with localization 1 and 2, but there is no significant difference in the overhead when we increase the localization from 2 to 3 for less than 15 nodes, Experimentation with more than 15 nodes has shown that the difference between the overhead with localization 2 and 3 widens with increase in number of nodes.

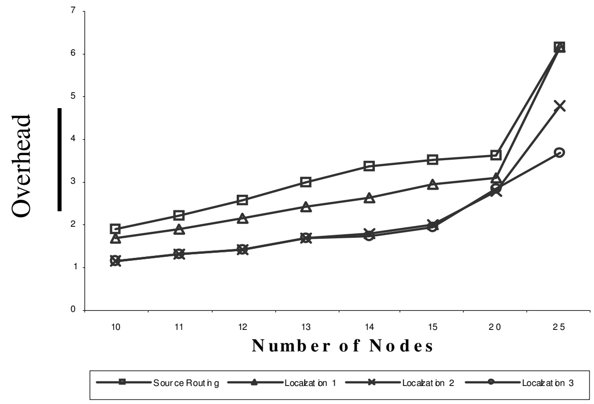

Fig. 6: Overhead vs number of nodes.

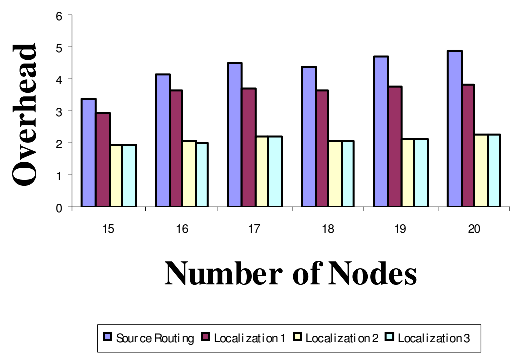

Fig 7: Overhead vs number of nodes for constant average path length.

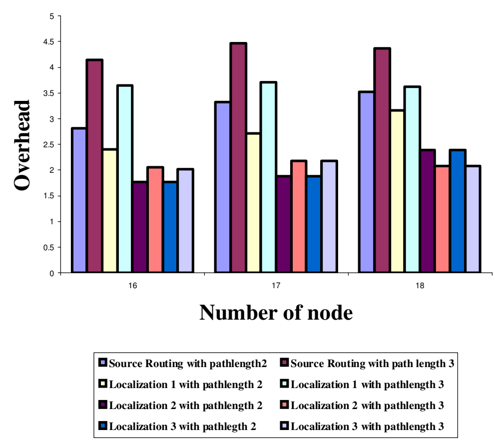

Fig 8: Overhead vs number of nodes for constant number of nodes but varying average path length

Fig 7. shows the overhead to number of nodes graph for a constant average path length 3 in the network. Here an interesting property exhibited by the algorithm is that even if the number of nodes increases overhead with localization remains nearly constant with constant path length showing the scalability of the approach. Fig 8.

shows the overhead for two different average path lengths 2 and 3. For the localization value 1, as the average path length increases, the overhead increases almost similarly in basic source routing and source routing with localization. Basic source routing and source routing with localization behave almost similarly for the localization value 1, because in this case the sub-tree of the route repairing node contains less number of nodes so the probability of the destination node to be found in this sub-tree is less, so this case eventually degenerates to the basis source routing.

7. Conclusion

This work explained the effects of applying mobility localization to the existing source routing approach for routing in an Adhoc Mobile Network. As shown by the results the solution is effective in decreasing the routing overhead by significant amount thus proving the hypothesis. With the increase in number of nodes the routing overhead does not grows exponentially. Ratio of localization versus average source route length is a factor which must be adjusted to minimize overhead.

Probabilty of finding a destination node in the neighborhood subtree determines the effectiveness of this approach. This probability is dependent on the dynamic nature of MANETs. If the nodes in the MANETs are mostly static and they are unreachable only if turned off this algorithm will not be effective. Localization value should be varied dynamically depending on the network state and feedback, which will be explored in future work.

8. References

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