Router Handoff: An approach for Preemptive Route Repair in Mobile Ad hoc Networks

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***Abstract*—Mobile Adhoc Networks (MANET) are distributed, mobile, wireless, multihop networks that operate without pre-existing communication infrastructure. Several routing protocols both reactive and pro-active have been proposed to provide the self starting behavior needed for adhoc networks.**

Unreliable wireless links and node mobility may result in a large number of route breakages. The standard approach followed in reactive routing protocols in case of broken routes is to flag an error and re-initiate route discovery either at the source or at an intermediate node. Repairing these broken links increases routing overhead and the delay in delivering packets.

In this paper, we propose an approach called Router Handoff which repairs routes preemptively, before they break, by using other nodes in the vicinity of a weak link. We have incorporated Router Handoff into the AODV routing protocol and have validated the idea through analysis and simulations. The results of the simulations indicate an increase in throughput under certain conditions. This improvement is a result of smaller overhead and delay. The approach may also be applied to other routing protocols with appropriate modifications

***Index Terms*—Mobile ad hoc networks, Routing, Router Handoff**

I. Introduction

A Mobile Adhoc Network (MANET) [1] is a cooperative engagement of a collection of mobile devices, herein referred to as *nodes*, without the required intervention of any centralized access point or existing infrastructure. Each node is equipped with a wireless transmitter and a receiver. In order to facilitate communication within the network, each node acts as a router and a routing protocol is used to discover and maintain routes between nodes. If only two nodes, located close to each other, are involved in the adhoc network, no real routing protocol or routing decisions are necessary. In many adhoc networks, two nodes that want to communicate may not be in the wireless transmission range of each other, but could communicate if nodes physically located between them are willing to forward packets.

Several routing protocols both reactive [2], [3] and proactive [4] have been proposed to provide the self starting behavior needed for adhoc networks. The performance of reactive protocols and their variants have been affected by *high routing overheads* and *delays* in the process of repairing broken routes. The current approach is to flag an error and re-initiate a route discovery either at the source or at an intermediate node where the route was broken, which in a reactive protocol typically involves flooding packets through the network. *Location Aided Routing* (LAR) [5] makes use of location information to reduce routing overheads. *Virtual Wire Messages* [6] and *Spine Routing* [7] make use of a Virtual Dynamic Backbone to reduce routing overheads. Several other approaches like caching of learned routes have also helped reduce routing overheads. But in all these approaches re-initiation of route discovery seems inevitable.

We present an approach called *Router Handoff* to preemptively repair routes that might break, using mobile nodes in the vicinity of the broken link. We have incorporated this idea into the AODV routing protocol. We also present a theoretical analysis of this approach where we compare AODV with Routing Handoff, plain AODV, and AODV with Local Route Repair (LRR). The analysis shows remarkable improvement in terms of reduction in both routing overhead and delay. The simulations validate our claims showing an increase in throughput as a result of smaller overhead and delay in repairing broken routes. This approach gives us better performance than the approach of rediscovering routes. The approach may also be applied to other routing protocols with appropriate modifications.

The main contribution of this paper is the preemptive technique of Router Handoff. Another contribution is the novel theoretical analysis of routing overhead and delays.

II. Router Handoff in AODV

Router handoff is a preemptive approach to deal with route breaks. In Router Handoff, each node makes use of its *Neighbor Information Table* (NIT). This table contains information about the status of links with each neighbour. The central idea of router handoff is to find an alternate node in the vicinity of a potential link break, which can bypass the weak link. A node which finds that it is routing traffic on a link that is about to break *hands off* its routing information to a suitable node when the ratio between received power on the link and the threshold receiving power is less than a particular *Handoff THreshold* (HTH).

When movement of an intermediate node or the destination may cause a link to break, a node which uses the link as the next hop broadcasts a *Handoff REQuest* (HREQ). HREQ is a single hop packet and contains the next hop node and all the previous hop nodes that use the link. When a neighbor node which receives the HREQ is in a position to route packets from some of the previous hop nodes to the next hop node, a decision made by using the NIT, it sends a *Handoff REPly* (HREP). The node also updates its routing table. The previous hop nodes, which receive the HREP update their routing tables to make the node which sent the HREP as the next hop, thereby avoiding the broken link. The HREP is a single hop packet.

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The advantage of this approach is that routes that may be about to break are repaired with just two packets HREQ and HREP. Since it tries to find an alternate route locally, before a route break, the delay involved is lower. Moreover more than one route can be fixed at a time.

A. Algorithm

The algorithm followed by each node in the network to perform routing handoff is outlined below. Timers prevent multiple back-to-back HREQs for the same routes. The details regarding timers and handling of multiple HREPs are omitted here for ease of presentation. Here `Received Packet` refers to data, routing or Hello Message packets. Hello Messages are used by nodes to discover neighbors and maintain the Neighbor Information Table. For each node in the network:

```
Begin
                ⋮
   if((Power of Received Packet/Threshold Power) < HTH)
   {
      Create Handoff Request Packet;
      Send Handoff Request Packet;
   }
   if(Received Packet == Handoff Request)
   {
      Check Neighbor Information Table;
      if(Next Hop Node in HREQ is a Neighbor)
      {
         if(Any Previous Hop Node in HREQ is a Neighbor)
         {
            Update Routing Table;
            Create Handoff Reply Packet;
            Send Handoff Reply Packet;
         }
      }
   }
   if(Received Packet == Handoff Reply)
   {
      if(Handoff Reply is for this Node)
      {
         Update Routing Table;
      }
   }
                ⋮
End
```

B. Example

To make the concept of routing handoff more concrete, consider the situation in Fig. 1. Let the route from source A to destination D pass through B and C, and the route from source E to destination D pass through . Now, if node C were to move, it could break either the link BC, or the link CD, or both.

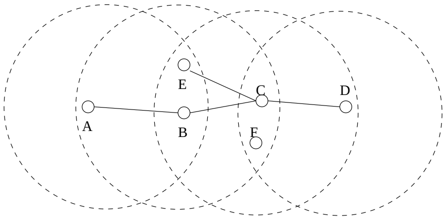


Fig. 1. AODV with Routing Handoff

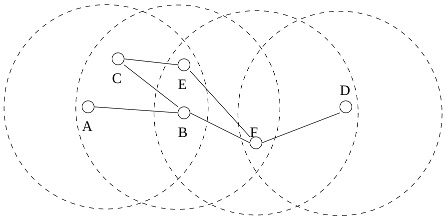


Fig. 2. Route Repair when the link CD breaks

Fig. 2 shows the scenario when the movement of C causes link CD to break. Before the the link CD is about to break, since node C has D as the next hop for some of the routes, it initiates a HREQ (refer Fig. 4 for the packet format). HREQ invites responses from nodes that are within range of D and either B or E. The hop count of the HREQ is 1 and reaches only immediate neighbours. Node F sees from its Neighborhood Information Table that it is within range of B, E and D, and sends a HREP (refer Fig. 5 for the packet format). HREP from node F indicates that it can route packets from B and E to D. The hop count of HREP is 1 and is received only by immediate neighbours of F. B and E on receiving the HREP update their routing tables so that F becomes the next hop for packets from sources A and source E. Figure 3 shows the scenario when the movement of C in Fig. 1 causes the link BC to break. Before the link BC is about to break, since node B has C as the next hop for some of the routes, it initiates a HREQ. The HREQ invites responses from nodes that are in the range of C and A. Node E infers from its Neighborhood Information Table that it is within range of C and A, and sends a HREP. The HREP from node E indicates that it can route packets from A to C. A on receiving the HREP updates its routing table so as to make node E as the next hop for the packets from source A.

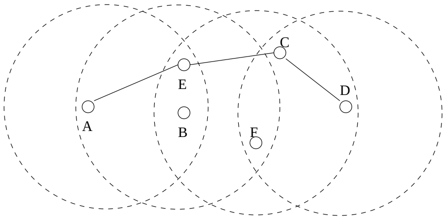


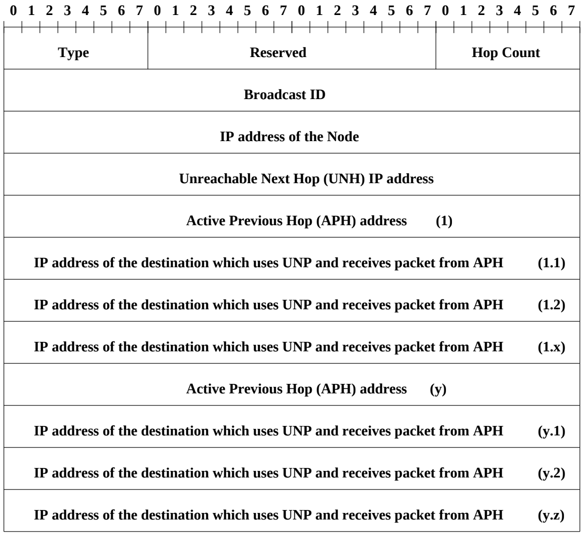
Fig. 3. Route Repair when the link BC breaks

C. Packet Formats

Packet formats for the HREQ and HREP messages are shown in figures 4 and 5 respectively.

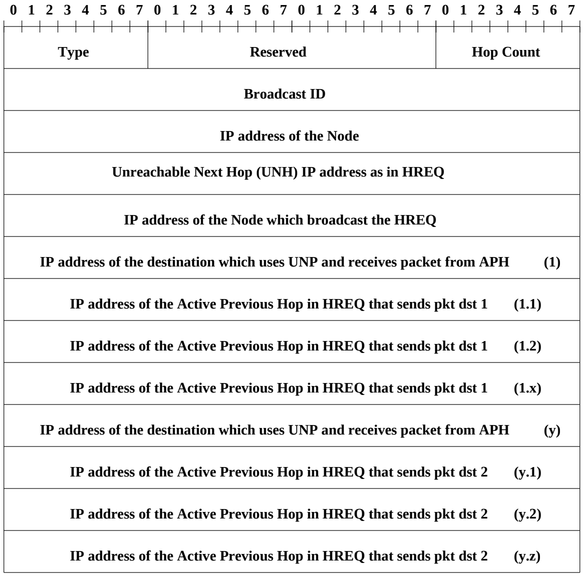
D. Computation of Handoff Threshold (HTH)

The idea in router handoff is to hand over routes and associated information before the link breaks. This is done



Type	Reserved	Hop Count
Broadcast ID		
IP address of the Node		
Unreachable Next Hop (UNH) IP address		
Active Previous Hop (APH) address (1)		
IP address of the destination which uses UNP and receives packet from APH (1.1)		
IP address of the destination which uses UNP and receives packet from APH (1.2)		
IP address of the destination which uses UNP and receives packet from APH (1.x)		
Active Previous Hop (APH) address (y)		
IP address of the destination which uses UNP and receives packet from APH (y.1)		
IP address of the destination which uses UNP and receives packet from APH (y.2)		
IP address of the destination which uses UNP and receives packet from APH (y.z)		

Fig. 4. Handoff REQuest Packet Format



Type	Reserved	Hop Count
Broadcast ID		
IP address of the Node		
Unreachable Next Hop (UNH) IP address as in HREQ		
IP address of the Node which broadcast the HREQ		
IP address of the destination which uses UNP and receives packet from APH (1)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 1 (1.1)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 1 (1.2)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 1 (1.x)		
IP address of the destination which uses UNP and receives packet from APH (y)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 2 (y.1)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 2 (y.2)		
IP address of the Active Previous Hop in HREQ that sends pkt dst 2 (y.z)		

Fig. 5. Handoff REPly Packet Format

by performing handoff when the ratio of the received power (RxPr) from a next hop node and the receive threshold power (RxThresh) of the received packet is less than Handoff Threshold (HTH).

$$\frac{\mathrm{RxPr}}{\mathrm{RxThresh}} \leq \mathrm{HTH} \tag{1}$$

Let t be the time required for router handoff to take place, s be the maximum speed of the node and d be the distance that can be covered during which the handoff is to take place (refer figure 6). We know that:

$$\text{Received Power} \propto \frac{1}{\text{distance}^4}$$

$$\mathrm{RxThresh} \propto \frac{1}{\mathrm{R}^4} \tag{2}$$

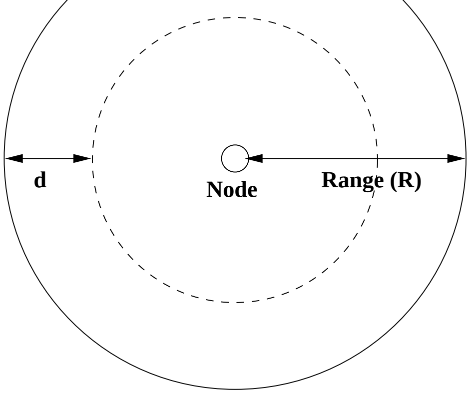


Fig. 6. A node in the annulus performs routing handoff

$$\mathrm{RxPr} \propto \frac{1}{(\mathrm{R}\text{ - }\mathrm{d})^4} \tag{3}$$

Substituting 2 and 3 in equation 1 we get

$$\frac{\mathrm{R}^4}{(\mathrm{R}\text{ - }\mathrm{d})^4} \leq \mathrm{HTH} \tag{4}$$

Substituting for d in equation 4 we have

$$\frac{\mathrm{R}^4}{(\mathrm{R}\text{ - }(\mathrm{s} * \mathrm{t}))^4} \leq \mathrm{HTH} \tag{5}$$

We use this result to compute HTH for a given network's degree of mobility and radio range.

III. THEORETICAL ANALYSIS

We first introduce the network model we use for analysis. The network model forms the basis for analysis of the approaches presented in earlier chapters. There is not much existing work on analysis of MANET routing protocols because of the dynamic nature of the network. Our analysis has been made easier since we concentrate on route repair.

A. Network Model

Let A be the area of the network under consideration. N is the number of nodes uniformly distributed over the network. Assuming each node in the network has the same transmitting power, the corresponding range of transmission is R. We assume a random traffic pattern: each source node initiates packets to randomly chosen destinations in the network. The expected length $\overline{L}$ for such traffic

$$\overline{L} = \frac{2\sqrt{A}}{3} \tag{6}$$

The above result is derived in section 4.1 of [8]. This result can be intuitively understood as follows. Since the nodes are uniformly distributed over the network, the number of nodes at a distance x from any node is proportional to x and the number of nodes within a circular radius of x

is proportional to x^2. This means the plot of the radius x versus number of nodes at distance x is a straight line passing through the origin. The slope of the straight line is immaterial for the analysis. The maximum distance is $\sqrt{A}$ for a square network with area A. Any node in the network can communicate with any other node in the network with equal probability. Then the probability of a node communicating with another node at a distance x is

$$p(x) = \frac{x}{\int_0^{\sqrt{A}} x dx}$$

Therefore the expected path length for a random traffic pattern is

$$\overline{L} = \int_0^{\sqrt{A}} x p(x) dx = \frac{2\sqrt{A}}{3}$$

When a link breaks let ϕ be the number of routes affected. Between any source destination pair, each of the links can break with equal probability. For our analysis, we do not take cached entries into account during route discovery. We also assume that that end-to-end delay on a route is proportional to the number of hops from source to destination.

B. Parameters

We analyze AODV, Local Route Repair and Routing Handoff with respect to the following parameters.

1. Number of packets involved in repairing a broken link (PKT)
2. Delay involved in repairing a broken link (DEL)

C. Basic Results

Here we show some basic results which forms the basis of our analysis. The results are based on the model stated in subsection A.

1. Number of packets involved in flooding the network:
   Here we assume that RREQ broadcasts reache all nodes in the network. Since each node forwards the RREQ packets only once, the number of broadcasts required is N. Hence the number of packets involved in flooding is N.
2. Number of hops H on the average to reach the destination:
   Since the expected path length is $\overline{L}$ and the transmission range is R, the number of hops required is

$$\begin{aligned} H &= \frac{\overline{L}}{R} \\ H &= \frac{2\sqrt{A}}{3R} \end{aligned} \tag{7}$$

3. Average number of hops (or time) to discover a route:
   From the above result the average number of hops to discover a route is $2H$.
4. Number of RERR broadcasts involved when a link breaks:
   Since our model assumes each of the H hops can break with equal probability, a link break closer to the source results in 1 RERR broadcast and a link break closer to the destination results in $H-1$ broadcasts, provided only one route is affected by the link breakage. Then the average number of RERR packets, per affected route.

$$\begin{aligned} k &= \frac{1+2+3+\ldots+H-1}{H} \\ &= \frac{H-1}{2} \\ &\approx \frac{H}{2} \\ k &= \frac{\sqrt{A}}{3R} \end{aligned} \tag{8}$$

But if ϕ routes are affected by a link breakage and the path from these sources to the point of link breakage do not overlap, maximum number of RERR broadcast required is

$$\begin{aligned} K &= \phi k \\ K &= \frac{\phi\sqrt{A}}{3R} \qquad K < N \end{aligned} \tag{9}$$

Note the the value of K is bounded by number of nodes in the network N. Such a scenario arises when a RERR broadcast ends up flooding the network.

D. Analysis of AODV

In AODV, a link failure causes a RERR broadcast to the sources affected. The source on receiving a RERR initiates a route discovery. The source may initiate a route discovery if it has a packet to send, here we assume it will.

1. Number of packets involved in repairing a broken route (PKT)
   PKT = RERR broadcast to the sources affected + flooding to discover the route for each route+ RREP unicast from the destination to the source

$$\begin{aligned} PKT &= K + \phi N + \phi H \\ &= \frac{\phi\sqrt{A}}{3R} + \phi N + \phi\frac{2\sqrt{A}}{3R} \end{aligned} \tag{10}$$

2. Delay involved in repairing a broken route (DEL)
   DEL = RERR broadcast to reach the source + RREQ to reach the destination + RREP to reach the source

$$\begin{aligned} DEL &= k + H + H \\ &= k + 2H \\ &= \frac{\sqrt{A}}{3R} + \frac{4\sqrt{A}}{3R} \\ &= \frac{5\sqrt{A}}{3R} \end{aligned} \tag{11}$$

E. Analysis of Local Route Repair

In AODV with local route repair we assume that the intermediate route discovery succeeds.

1. Number of packets involved in repairing a broken route (PKT)
   PKT = RERR broadcast + flooding to discover the route for each route + RREP unicast from destination to the intermediate node

$$
\begin{aligned}
PKT &= K + \phi N + \frac{\phi\sqrt{A}}{3R} \\
&= \frac{\phi\sqrt{A}}{3R} + \phi N + \phi\frac{\sqrt{A}}{3R} \qquad (12)
\end{aligned}
$$

2. Delay involved in repairing a broken route (DEL)
   Delay involved in repairing a broken route = RREQ to reach the destination + RREP to reach the intermediate node

$$
\begin{aligned}
DEL &= \frac{H}{2} + \frac{H}{2} \\
&= H \\
&= \frac{2\sqrt{A}}{3R} \qquad (13)
\end{aligned}
$$

F. Analysis of Routing Handoff

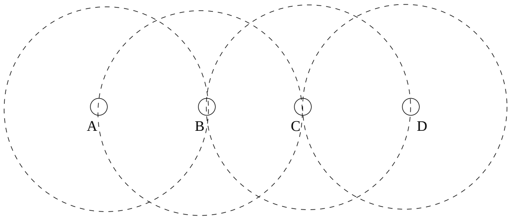


Fig. 7. Non overlapping transmission ranges of nodes A, B, C, D

For analysis of Router Handoff, we need a criterion to determine if there exists a suitable node for handoff to occur. Consider a section of the network as shown is Figure 7. When node C moves, it is not possible to find another node that will take the responsibility of routing packets from B to D (unless of course a new node moves to the original position of C). The point to note here is that certain amount of overlapping of transmission ranges of B and D is required. This alone will not suffice. We also need nodes in the overlapping area that will take up the responsibility of routing packets from B to D as in Figure 8.

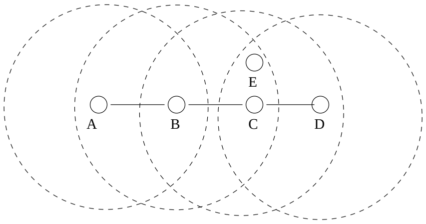


Fig. 8. Overlapping transmission ranges of nodes A, B, C, D

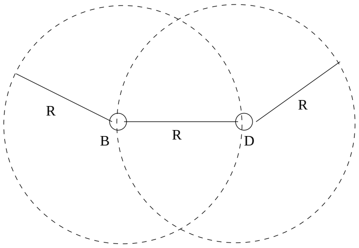


Fig. 9. Maximum overlapping possible between node B and D

The maximum extent of overlapping between nodes B and D, should be less than shown in Figure 9, or else we would not have used node C to relay the packets to D. The overlapping area will be less than $1.23R^2$. Since the nodes are uniformly distributed over the network, the number of nodes in the overlapping area

$$
\eta \leq \frac{1.23R^2N}{A} \qquad \text{and} \qquad \eta \geq 2 \qquad (14)
$$

$$
N \geq \frac{\eta A}{1.23R^2} \qquad (15)
$$

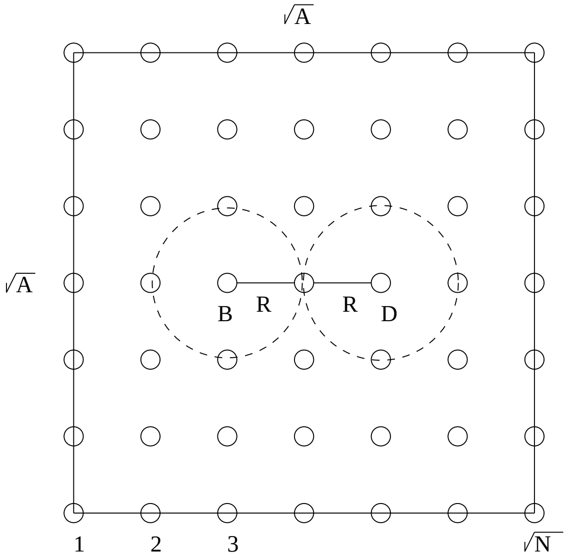


Fig. 10. Snapshot of our Network Model

Equation 15 provides us the condition under which nodes will be present in the overlapping area. But to ensure that the transmission ranges of B and D overlap, consider Figure 10 which is a representative snapshot of our model. For the transmission range of B and D to overlap,

$$
\begin{aligned}
R &> \frac{\sqrt{A}}{\sqrt{N}} \\
N &> \frac{A}{R^2} \qquad (16)
\end{aligned}
$$

which is essentially similar to equation 15.

1. Number of packets involved in repairing a broken link (PKT)

Number of packets involved in repairing a broken link = HREQ + HREP

$$\begin{aligned} PKT &= 1+1 \\ &= 2 \end{aligned} \tag{17}$$

2. Delay involved in repairing a broken link (DEL)
   Delay involved in repairing a broken link = HREQ + HREP

$$\begin{aligned} DEL &= 1+1 \\ &= 2 \end{aligned} \tag{18}$$

These results of the analysis of Router Handoff apply only when a suitable node is available for handoff. In practice, such a node may not always be present.

IV. Experiments

For the purpose of simulation we use the ns-2.1b8a network simulator [9]. The simulation results for AODV, AODV with Local Route Repair (LRR) and AODV with Router Handoff are presented here. We conducted the simulations on networks with 25, 50 and 75 nodes. The transmission range of each node was 250 mts. We ran the simulations for a period of 200 seconds. Routing overhead for AODV and LRR is the sum of RREQ, RREP and RERR packets broadcast. Routing overhead for AODV with Router Handoff is the sum of RREQ, RREP, RERR, HREQ and HREP packets. We subject each network to two different scenarios. One with low mobility and the other with high mobility. In each case the time required to perform routing handoff is approximately 0.6 seconds. HRQ_ID is set to 4 sec and HRP_ID is set to 0.1 sec for the simulation.

In the low mobility scenario, the minimum pause time is 5 seconds and maximum pause time is 10 seconds. The speed of the node varies between 20 m/s to 40 m/s. The value of Handoff Threshold (HTH) is computed according to equation 5 and is set to 1.5.

In the high mobility scenario, the minimum pause time is 1 seconds and maximum pause time is 5 seconds. The speed of the node varies between 40 m/s to 60 m/s. The value of Handoff Threshold (HTH) is computed according to equation 5 and is set to 2.

A. 25 Nodes

For a network with 25 Nodes and satisfying the criterion in equation 16 we set the area to 950 × 950 sq mts. The network is subjected to traffic with 15 TCP connections in one simulation and 15 UDP connections in another simulation for both low and high mobility scenarios.

Connection Type	AODV	LRR	HANDOFF
TCP	24607	23891	25580
UDP	18009	14695	16756

TABLE I

Packets received for 25 Nodes (low mobility)

Connection type	AODV	LRR	HANDOFF
TCP	79760	74753	75984
UDP	77098	80416	73842

TABLE II

Routing overhead (pkts) for 25 Nodes (low mobility)

Connection Type	AODV	LRR	HANDOFF
TCP	27239	25060	21622
UDP	13704	12146	16397

TABLE III

Packets received for 25 Nodes (high mobility)

Connection Type	AODV	LRR	HANDOFF
TCP	74115	81994	72293
UDP	84310	89169	78359

TABLE IV

Routing overhead (pkts) for 25 Nodes under (high mobility)

B. 50 Nodes

For a network with 50 nodes and satisfying the criterion in equation 16 we set the area to 1650 × 1650 sq mts. The network is subjected to traffic with 30 TCP connections in one simulation and 30 UDP connections in another simulation for both low and high mobility scenario.

Connection type	AODV	LRR	HANDOFF
TCP	17166	16230	20949
UDP	13995	11034	15028

TABLE V

Packets received for 50 Nodes (low mobility)

Connections type	AODV	LRR	HANDOFF
TCP	89813	96044	101642
UDP	155261	175389	146763

TABLE VI

Routing overhead (pkts) for 50 Nodes (low mobility)

Connection type	AODV	LRR	HANDOFF
TCP	18169	18897	21718
UDP	9611	9268	12035

TABLE VII

Packets received for 50 Nodes (high mobility)

Connection type	AODV	LRR	HANDOFF
TCP	80187	89285	90902
UDP	159121	177173	154005

TABLE VIII
Routing overhead (pkts) for 50 Nodes (high mobility)

C. 75 Nodes

For a network with 75 nodes and satisfying the criterion in equation 16 we set the area to 1950 × 1950 sq mts. The network is subjected to traffic with 45 TCP connections in one simulation and 45 UDP connections in another simulation for both low and high mobility scenarios.

Connection type	AODV	LRR	HANDOFF
TCP	25815	20469	27379
UDP	17285	14956	17126

TABLE IX
Packets received for 75 Nodes (low mobility)

Connections type	AODV	LRR	HANDOFF
TCP	136429	139423	138508
UDP	247496	273278	244958

TABLE X
Routing overhead (pkts) for 75 Nodes (low mobility)

Connection type	AODV	LRR	HANDOFF
TCP	26738	24212	28757
UDP	17422	15651	17303

TABLE XI
Packets received for 75 Nodes (high mobility)

Connection type	AODV	LRR	HANDOFF
TCP	121961	123487	128777
UDP	245377	264987	248826

TABLE XII
Routing overhead (pkts) for 75 Nodes (high mobility)

D. 25 Nodes with larger Area

The criterion in equation 16 restricts a network with 25 nodes to an area of 950 × 950 sq mts. We now examine the effects when this is violated. Here we consider a network with 25 nodes and area 1200 × 1200 sq mts.The network is subjected to traffic with 15 TCP connections in one simulation and 15 UDP connections in another simulation for both low and high mobility scenario.

Connection type	AODV	LRR	HANDOFF
TCP	14834	16601	19642
UDP	14935	14276	14586

TABLE XIII
Packets received for 25 Nodes (low mobility, large Area)

Connection type	AODV	LRR	HANDOFF
TCP	48700	53806	56722
UDP	49454	58219	53720

TABLE XIV
Routing overhead (pkts) for 25 Nodes (low mobility, large Area)

Connection type	AODV	LRR	HANDOFF
TCP	13932	10829	7952
UDP	9570	8660	10341

TABLE XV
TCP packets received for 25 Nodes (high mobility, large area)

Connection type	AODV	LRR	HANDOFF
TCP	47565	38480	32362
UDP	57879	65163	60465

TABLE XVI
Routing overhead (pkts) for 25 Nodes (high mobility, large area)

E. 50 Nodes with larger Area

The criterion in equation 16 restricts a network with 50 nodes to an area of 1350 × 1350 sq mts. We now examine the effects when this criterion is violated. We consider a network with 50 nodes and area 1600 × 1600 sq mts.The network is subjected to traffic with 30 TCP connections in one simulation and 30 UDP connections in another simulation for both low and high mobility scenarios.

Connection type	AODV	LRR	HANDOFF
TCP	15540	14945	15549
UDP	13466	9649	12977

TABLE XVII
Packets received for 50 Nodes (low mobility, large area)

Connections type	AODV	LRR	HANDOFF
TCP	69284	68039	69398
UDP	116519	138322	112813

TABLE XVIII
Routing overhead (pkts) for 50 Nodes (low mobility, large area)

Connection type	AODV	LRR	HANDOFF
TCP	17032	13729	15244
UDP	12470	10727	14015

TABLE XIX
Packets received for 50 Nodes (high mobility, large area)

Connection type	AODV	LRR	HANDOFF
TCP	81477	76796	73526
UDP	114385	136827	118014

TABLE XX
Routing overhead (pkts) for 50 Nodes (high mobility, large area)

F. 75 Nodes with Large Area

The criterion in equation 16 restricts a network with 75 nodes to an area of 1650 × 1650 sq mts. We now examine the effects when this criterion is violated. We consider a network with 75 nodes and area 2000 × 2000 sq mts.The network is subjected to traffic with 45 TCP connections in one simulation and 45 UDP connections in another simulation for both low and high mobility scenario.

Connection type	AODV	LRR	HANDOFF
TCP	20690	21590	24285
UDP	19239	15691	18164

TABLE XXI
Packets received for 75 Nodes (low mobility, large area)

Connections type	AODV	LRR	HANDOFF
TCP	114231	121442	126846
UDP	197533	214771	195026

TABLE XXII
Routing overhead (pkts) for 75 Nodes (low mobility, large area)

Connection type	AODV	LRR	HANDOFF
TCP	23799	23032	23280
UDP	11078	9270	9593

TABLE XXIII
Packets received for 75 Nodes (high mobility, large area)

Connection type	AODV	LRR	HANDOFF
TCP	109581	108535	105128
UDP	191457	215922	206055

TABLE XXIV
Routing overhead (pkts) for 75 Nodes (high mobility, large area)

Using Network throughput and routing overheads as a measure of performance, We can conclude the following from the results of the simulations:

- AODV with Router Handoff performs better than AODV with local route repair when the network conforms to the criterion in equation 16.
- AODV with Router Handoff performs as well or better than AODV when the network conforms to the criterion in equation 16.
- AODV with Router Handoff performs erratically with respect to AODV and LRR when the criterion in equation 16 is violated.

V. Related Work

To the best of our knowledge, the only work directly related to the work presented in this paper is "Preemptive Routing"[10]. Preemptive routing keeps track of signal strengths and resorts to route recovery procedures before a link breaks. The difference between Router Handoff and Preemptive Routing is that the latter does a normal route recovery procedure involving flooding whereas Router Handoff tries to locally find an alternate node and hands off existing routing information to it using only two broadcasts. Of the two techniques, Router Handoff reduces overheads of route repair and both Router Handoff and Preemptive Routing attempt to reduce delays due to route breakages.

VI. Conclusion

In this paper we presented an approach called Router Handoff as a preemptive method of preserving routes in the presence of link breakages. Theoretical analysis of the approach has provided us with a criterion for better performance using this approach.

Simulation results show that AODV with Router Handoff performs better than plain AODV and AODV with Local Route Repair when the the network satisfies certain conditions. This gain in performance is due to reduction in routing overheads and route repair delays.

We also believe that other reactive protocols could benefit from incorporating Router Handoff. This would be an interesting area for future work.

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