An Opportunistic Routing Augmentation for Reliable Routing on AODV in MANETs

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Abstract**—***Ad hoc On-Demand Distance Vector (AODV) routing protocol was designed for Mobile Ad Hoc Networks (MANETs), and it is currently extensively used for the operation of MANETs. The mobile nature of the nodes in the network arouses the need for reliability in the network communication, which has been a great challenge all along and is still being resolved. In this work, we present the AODV enhancement for Reliable Reactive Routing in Mobile Ad hoc Networks to increase the resilience to link dynamics and to provide good throughput during mobility. The R3E scheme was designed to enhance the existing reactive routing protocols to provide reliable and energy efficient packet delivery against the unreliable wireless links by utilizing the technique of local path diversity. An enhancement of this scheme to provide reliable communication for mobile nodes is proposed here, along with the simulation analysis performed in the Network Simulator.*

Index Terms**—***Computer network reliability, Mobile Ad hoc networks, routing protocols, throughput, wireless communication.*

I. Introduction

Mobile Ad hoc networks are used extensively in the growing technology where the world is moving towards portability. MANETs have found their applications in various fields like military, education, commerce and entertainment. Ad hoc Applications are used for war control, environmental monitoring, disaster management, virtual learning, etc. When highly confidential and vital information is being transferred among the nodes of the network, it is essential for the nodes to reliably transmit the data.

Routing protocols in MANETs are generally classified as proactive and reactive [1]. The reactive routing protocols [2-6] can also be called as On-Demand protocols. The route discovery process is initiated when the need for transmission arises. The broadcasting of RREQ and RREP messages takes place during this period. The purpose of RREQ message is to discover a route from source to destination node. So when the destination node gets a RREQ message, it sends RREP message along the established path.

In this paper, we first propose the application of R3E [9] in Mobile Ad hoc networks with a new algorithm to suit the Mobile nature of the nodes. Without optimal changes, it is not possible to apply R3E on MANETs as the static nature of wireless sensor nodes are exploited to obtain a direct path called as guide path that helps in finding a co-operative reliable path for data transmission from a source to destination.

The main contributions of this work are listed below:

- Modeling Reliable routing mechanism for a Mobile Ad hoc network using AODV and R3E
- Opportunistic Route Repair mechanism for handling link failures in the network using Received signal strength and Link residual life

II. Related Work

The works related to the reliable routing mechanism are discussed in this section.

On-demand protocols minimize the complete number of hops of the selected path and they are also very good on single rate networks. There are many reactive routing protocols, like ad-hoc on-demand distance vector (AODV) [7], dynamic source routing (DSR) [4], temporally order routing algorithm (TORA) [5], Associativity-based routing (ABR) [11], signal stability-based adaptive (SSA) [8], and relative distance micro-discovery ad-hoc routing (RDMAR) [2].

On the contrary, proactive or table-driven protocols [8-12] portray a mechanism to dynamically update the local routing information from all possibilities for all possible nodes of the network. Proactive approach refers to the process of maintaining the routing tables even before the need arises. Here, handling route requests is much easy by just pulling out one for the shortest route to the destination from the table, which is one of the main reasons why there arises a bandwidth deficiency in MANETs. Also, there is a great disadvantage that huge amount of overhead is being generated during the transmission and reception of control messages in order to update the routing tables [3]. Some of the proactive routing protocols are destination sequenced and Optimized link state routing (OLSR) [8], wireless routing protocol (WRP) [9], Cluster head gateway switch routing (CGSR) [10], fisheye state routing (FSR) [11] and distance vector (DSDV) [12]. Most of these routing protocols focuses only on distance, data packets re-transmission, power and minimum cost.

The protocols that have guaranteed reliability add to the motive of this research work due to the following reasons. A Reliable routing algorithm for Mobile Ad hoc Networks based on fuzzy logic [13] does not consider the mobility of MANETs; Optimized and Reliable AODV for MANET [14] encourages a re-transmission technique rather than a proactive one that guarantees reliable data transmission. An Improvement of AODV Protocol Based on Reliable Delivery in Mobile Ad hoc Networks [16] is a good technique for data transmission reliability, however, the R3E: Reliable Reactive Routing Enhancement for Wireless Sensor Networks [16] has provided both reliability and energy-efficient packet delivery against the unreliable wireless links.

The self healing nodes [17] proposed by Venkatraman, the route overhead based deterministic routing [18] by Timo, the integrated energy aware routing [19] by Tamilarasi and the AODV-BRL [20] proposed by Liu Yujun provides solutions to reliability related issues in MANETs. The Network Sender Multicast Routing Protocol [21] provides multicasting solution with reliability and scalability under consideration. Most of these methods either induce delay, overhead or both. The trust enhanced routing technique [22] proposed by Salmanian, the agent based multicast routing scheme [23] by Biradar and the reliable probabilistic grid routing algorithm [24] by Zhengyu Wu are also pertaining to reliability; however, accuracy is probabilistic in nature.

Some of the opportunistic routing methods available are [25] and [26]. ExOR: opportunistic multi-hop routing for wireless networks [27] is one reliable method where the focus is on the data delivery.

The calculations and equations utilized by the proposed scheme are listed and discussed below.

- *Backoff Delay*

The decision making module considers a backoff delay parameter that is essential. Let t_{ij} denote the backoff delay at the current forwarding node v_j, which receives an RREQ from v_i. The value of t_{ij} is calculated as defined below.

$$t_{ij} = \frac{HopCount}{\sum_k P_{ik} P_{kj} + 1} . T, vk \in H(i, j) \quad (1)$$

- *Received Signal Strength*

The RSS value is used to denote the power level in the received signal. The RSS value is directly proportional to the distance between the transmitter and the receiver antenna. The packet receive ratio is used to find the next forwarding node according to [16] which is obtained from the RSS equation. The standard formula is used to find the power level in the signal is as follows.

$$RSS = \frac{T_p G_t G_r Ht^2 Hr^2}{d^4} \quad (2)$$

Where,

T_p → Transmission Power
G_t →Transmitter Gain
G_r →Receiver Gain
Ht →Height of the transmitter antenna
Hr →Height of the Receiver antenna
d → Distance between source and destination

III. Architecture of the Proposed Work

The architectural diagram of the proposed work in terms of the tasks performed during the handshake process is described in Figure 2 below. The provision of the opportunistic routing as an available alternative to the overall architecture is shown; also the fact that all the processes are mobility aware brings novelty to the architecture.

The source sends a route request packet and receives a route reply about the shortest path to the destination. This was called as the guide path and this is not the actual routing path to the destination.

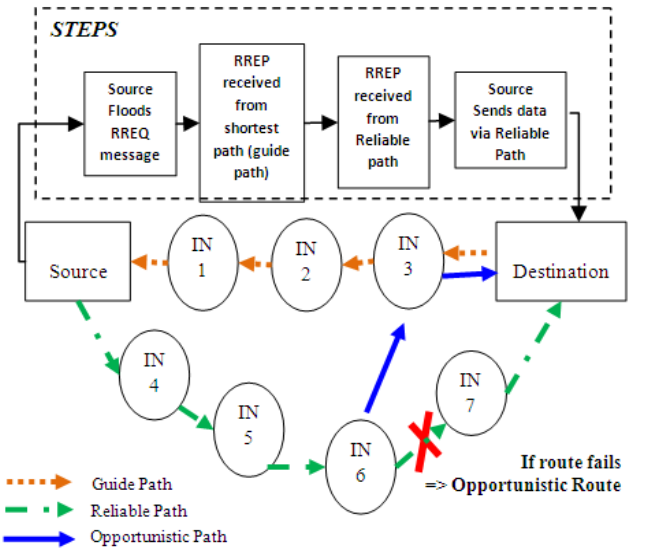

Figure 2. Architectural block diagram of AODV-R3E for MANETs

The route reply marks the nodes as guide nodes while returning from the destination to the source. This is the normal working of the R3E scheme, in order to reduce the delay in the network during route reconstruction if any link failure occurs; we introduce opportunistic routing on the occurrence of link failure. This is mainly in order to reduce the route reconstruction delay. Hence the Route Error message is handled in an opportunistic way by the previous hop to the link that has failed.

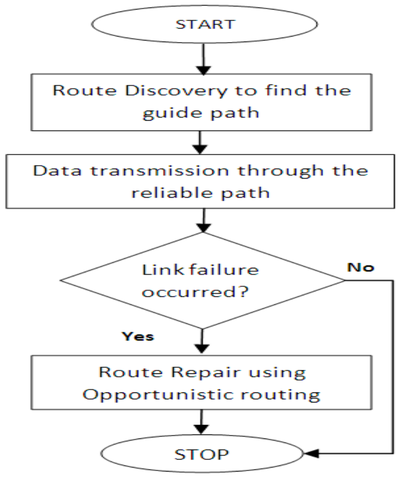

Figure 3. Flow of operations in AODV-R3E for MANETs

The proposed scheme AODV-R3E for MANETs performs route discovery process similar to R3E scheme with an additional enhancement of distinguishing mobility through the RSS, a simplified working flow of which is described in Figure 3.

It is vital to note that mobility is considered at every stage of the flow explained in Figure 3. The detailed description of how mobility is considered is explained further in the following sections. Also opportunistic routing on node failure occurrence is another major enhancement here.

The mobility rate of a node can be defined as the change in RSS from a node per unit time. It is given by the equation (3).

$$M_o = \frac{RSS_k - RSS_{k-i}}{i} \quad (3)$$

Where k is the instant of time, and i is the time interval between the current and the previous instants. The mobility factor of a node indicates its reliability. The significant mobility constraints are: measurement of RSS may not be accurate when the M_o varies rapidly with time; RSS measurement may be affected by presence of interference in the network and environmental obstacles may also induce fading.

IV. Working of the Proposed Scheme

The working of the proposed scheme can be divided into the route discovery and the route error handling mechanisms are the main modules that are explained below.

A. *Route Discovery [RREQ and RREP]*

The route discovery process is different from that of the work proposed in [16] as it considers the network mobility.

- *Route Request (RREQ) propagation*

When data wants to be sent by a source node to a destination, the route request message is initially sent to its neighbouring nodes. Now, instead of broadcasting again the RREQ via the existing routing protocols, the RREQ packets are flooded towards the destination from its neighbouring nodes. A biased backoff counter as in equation (1) is to used to intentionally amplify the differences of RREQ's traversing delays along different paths. The propagation of route request is shown in Figure 4 below.

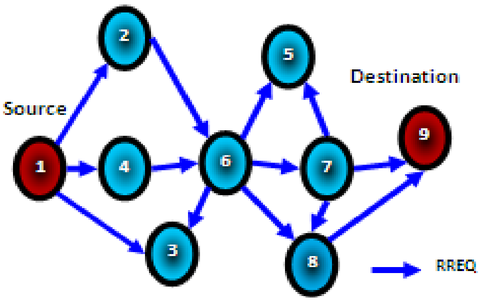

Figure 4. Propagation of RREQ

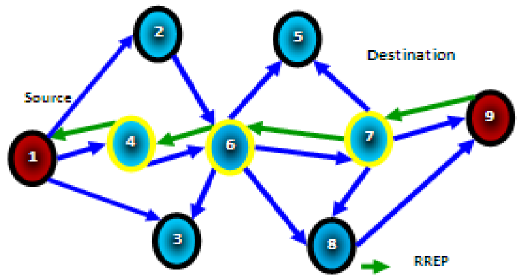

Figure 5. Propagation of RREP

- *Route Reply (RREP) propagation:*

When a route reply comes back from the destination to the source, on its way back, it marks all the nodes that forward the RREP as guide nodes. The guide nodes are chosen also considering the equation (3) that indicates mobility rate for a node based on the change in RSS per unit time. The rationale is that the less mobile nodes are more reliable in MANETs.

The change in RSS is calculated for every node using equation (2) while it is considered for the guide node. This is to ensure that the guide path remains longer as a reference for the co-operative forwarding to take place through the reliable path. As all the nodes are mobile, it is important to choose the gui de path to be quite stable while the nodes are in a hurry to move around in the network. This is illustrated in Figure 5 and the nodes 4, 6 and 7 marked in yellow are the guide nodes that are marked by the RREP when travelling from the destination to the source.

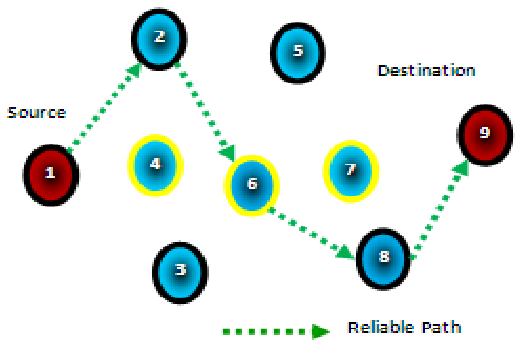

Figure 6. Reliable Routing

B. *Route Error Message (RERR) handling Mechanism*

In AODV, if failure occurs in any route then the reconstruction of the route takes place by transmitting a Route Error Message RERR to the source, which begins the route reconstruction all over again. This means construction of the guide path and the actual path right from the beginning which consumes additional time and resources. In a highly mobile environment, it is not good enough to keep finding the guide routes as the guide path remains only for a short period of time before the move out of each others' range.

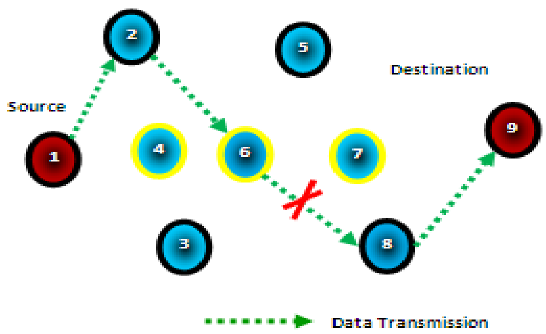

Figure 7. Occurrence of RREP

Hence equation (3) and (4) are used to obtain the link residual life for a node through which opportunistic routing is achieved. Unlike AODV, when a link failure occurs, the route error message is sent to the node in the path of previous hop in which current data transmission takes place, instead of forwarding to the source.

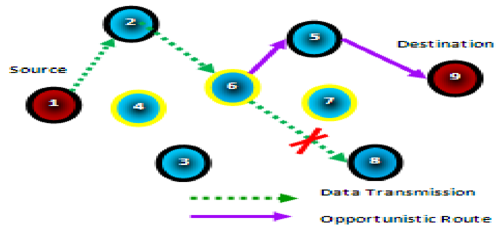

Figure 8. Opportunistic Route Repair Mechanism

The node in the previous hop finds a path to the destination using opportunistic routing with the available residual life information of the link. This situation arises only if the link failure occurs. Else, the data would just go from the reliable path. The Figure 8 clearly shows that the nodes 6 and 8 go out of each other's range and the communication between them fails due to link breakage. This is a common challenge faced in MANETs. Equation (3) is used to verify the mobility of the neighbouring nodes of node 6 and data transmission takes place to the destination in an opportunistic manner. There are three cases in which this can take place.

Case 1: Link failure at reliable path.

Link failure at the reliable path is shown in Figure 7, where the link between the reliable path node 6 and 8 breaks. There are two options for the routing continuation: one is through the guide path and another through the nodes that are not part of the reliable path nor guide path. The rerouting begins from the previous hop (i.e. the last hop until which data has travelled) as in the algorithm.

Case 2: Link failure at the guide path.

If the M_o value is low for a particular node and the link residual life is high for a node that is part of the guide path, then the node will be chosen for the reliable route as well. During this case the link failure may occur at the guide path which is also the reliable path. During this case, the last hop until which data has propagated initiates the rerouting process.

Case 3: Link failure at the opportunistic path

As a result of the rerouting process the opportunistic path to reach the destination is determined. This does not guarantee that a failure at the opportunistic route will never occur. The rerouting process is still initiated as in case 1 and 2 until the data reaches the destination. So there may not at all be a situation where the source gets to perform route discovery process again. The guide path is always a reference to reach the destination irrespective of whether it may or may not be the reliable path.

The algorithm used in all three cases is the same and it is given below:

```
Store RR(i,j) ← Reliable route to destination
Let d(so,sn) = distance from source to destination
Rd = remaining distance to destination at current instant
if {no connectivity between RR(i,j) and RR(i+1,j+1)} {
        Find the next available neighbour from the
information available in RREP
        if no availability of nodes {
                Send RERR to previous hop; /*Decrement
sequence number and send RREP
                if {Rd<= f*d(so,sn)} {
                Perform opportunistic routing to
        destination
                } else {
                Begin Reliable route discovery to
destination from current hop
                }
                end if-else
        }
        end-if
}
end
```

The above algorithm sends RERR message to the previous hop so that the opportunistic routing is begun only if the data has travelled over 75% of the entire distance from the source to the destination by setting the fraction f as 0.25. In order to keep the reliability, the reliable route discovery is begun from the current hop (node at which there is an unavailability of next-node) if the data has not yet travelled 75% of the entire path distance form source to destination.

V. Simulation Results

The simulation is done using the simulator NS2. Network simulator is a definite event-time driven simulator. NS2 is an open source software which uses C++ and Tool Command Language (TCL) for the purpose of simulation. C++ is used for packet processing and is fast to run. TCL is used for simulation description and to manipulate existing C++ objects. For this reason, NS2 is widely used to simulate the networking concepts. This software is extensively used for research purposes especially to design protocols and routing schemes. The simulation parameter used in the simulation is tabulated in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Channel Type	Wireless Channel
Radio Propagation model	TwoRayGround
Network interface type	WirelessPhy
MAC Type	IEEE 802.11
Antenna Model	Omni Antenna
Simulation Area	500 X 500m
Routing Protocol	AODV
Simulation Time	100 ms
Traffic Model	CBR

Mobility Model	Random Way Point
Speed	10 m/s to 50 m/s
Transmission Range	250m

- *Packet delivery Ratio*

The packet delivery ratio is one among the Quality of Service (QoS) metric to evaluate the performance of network. Low packet delivery ratio wipes out the network performance. Figure 9 shows that proposed system has good packet delivery ratio. The formula used for calculated packet delivery ratio is shown in equation (4).

$$PktDelivery\% = \frac{\sum_{1}^{n} CBR_{recv}}{\sum_{1}^{n} CBR_{sent}} \quad (4)$$

The Packet delivery in number of packets is measured which is illustrated in the graph below.

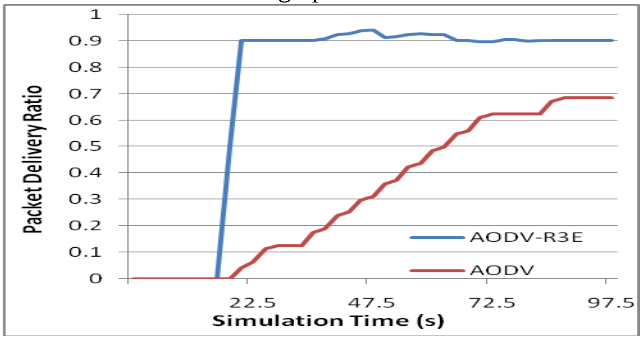

Figure 9. Packet Delivery Ratio

- *Packet Loss ratio*

The Packet Loss ratio is defined as the maximum number of packets that can be dropped by a node.

Figure 10 shows that the packet loss is optimal during the data transmission. The equation (4) is used to obtain the packets lost.

$$PacketsLost = CBR_{sent} - CBR_{recv} \quad (3)$$

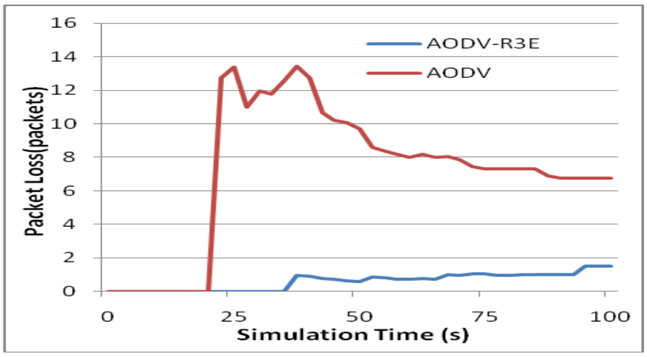

Figure 10. Packet Loss Ratio

- *Packet Delay*

The delay happened during data transmission in a network is known as the Packet Delay as shown in Figure 11. The graph shows that the overall delay caused by AODV-R3E is less than the AODV, although some delay is found during the route establishment phase. During occurrences of link failures, instead of routing from the source, the opportunistic routing mechanism proposed here reduces the delay to a considerable extent which is visible in the graph that follows.

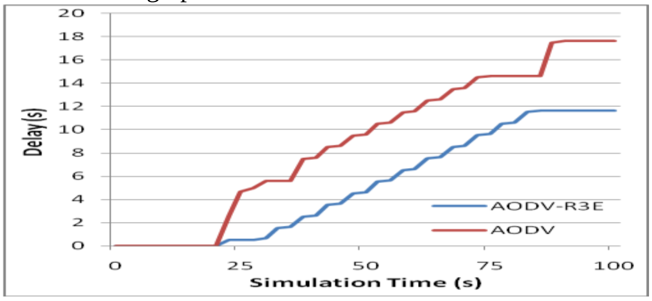

Figure 11. Packet Delay Ratio

- *Mobility*

Mobility analysis gives us how well the proposed scheme handles the speed of the node motion in the network.

Average throughput is obtained with the mobility at different speeds of node movement and is plotted against the different speed values. The graph in Figure 12 shows that AODV-R3E has good throughput even though the mobility is increasing.

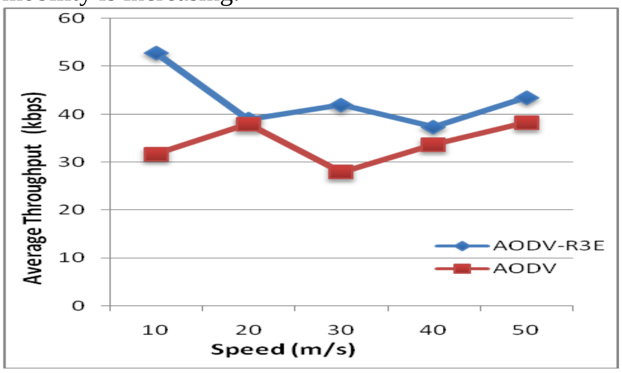

Figure 12. Mobility Vs Throughput

VI. Conclusion

To sustain the mobility and yet transfer data between nodes in a reliable manner, this paper provided an enhanced R3E scheme to suit the mobile ad hoc networks. Mobility in adhoc networks is considered a great demand factor. An opportunistic route restore mechanism is implemented with link residual life of the nodes considering the mobility factor of the guide path and the reliable path. The proposed scheme performs well in the network considered and can hence be used for reliable transmission in MANETs. Also, the opportunistic mechanism is only taken into effect when a link failure occurs. Since this scheme aims at reliable transmission to avoid link failures, the route repairing mechanism occurs rarely in the system.

For future research, the energy efficiency of the system can be monitored and improved in highly mobile environments. A real time implementation of the proposed R3E augmentation for Mobile Ad hoc Networks is also possible by employing communications between robots.

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