Performance study of AODV routing protocol using ETX as a metric

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Abstract - Due to unstable link states and interference between neighbour nodes, routing in wireless mesh network (WMN) is much more complicated and unpredictable than wired network. As the simplest and most primitive routing metric, hop count does not always work well in WMN where routing with least hop count does not bring the best performance. Recent research shows that radio metrics, such as ETX reflect more accurately the link conditions in a mesh network in terms of delay, loss, bandwidth, and so on. The ETX metric routing method is used with a cross-layer design taking the asymmetry of a wireless link into account, in which monitoring and measurement functions provide metrics in both forward and reverse directions and captures the link state between the node and each of its neighbours. This method is applied to Ad-hoc On-demand Distance Vector (AODV) routing protocol during the route discovering operation. AODV-ETX finds the best path based on value of the ETX by sending the probe packets to find the delivery ratios in the forward and reverse directions, from source to destination and from destination to source respectively. We evaluate performance of the AODV-ETX protocol using NS-2 simulator. The results show that the AODV-ETX outperforms the original AODV, where the results show a significant reduction of delay compared to the original AODV and also the packet delivery ratio is comparable to the packet delivery ratio in the original AODV.

Keywords: AODV, ETX, internetwork, MAC, Mesh topology, Network traffic, NS-2.34, Radio nodes, X-graphs

I. INTRODUCTION

Wireless Networks have been an emerging technology in recent years due to their attributes such as flexibility, high robustness and bandwidth efficiency. There are many kinds of wireless topologies and wireless mesh networks (WMN) is one among them. Recently, wireless mesh networks have attracted much attention. Wireless mesh networks is a communications network made up of radio nodes organized in a mesh topology. A mesh network is reliable and offers redundancy. Wireless mesh networks can self form and self heal. Such networks, also known as ‘‘community wireless networks’’, can be used for various applications such as shared broadband access, neighbourhood gaming, video surveillance, and media repository.

In wireless mesh networks data will hop from one device to another until it reaches its destination. Dynamic routing algorithms implemented in each device allow this to happen. To implement such dynamic routing protocols, each device needs to communicate routing information to other devices in the network. Each device then determines what to do with the data it receives — either pass it on to the next device or keep it, depending on the protocol. The routing algorithm used should attempt to always ensure that the data takes the most appropriate (fastest) route to its destination. Routing refers to the process of selecting paths in a network along which to send network traffic. Routing involves two basic activities: determining optimal routing paths and forwarding packets through an internetwork. The routing process usually directs forwarding on the basis of routing tables which maintain a record of the routes to various network destinations. Constructing routing tables, which are held in the router's memory, is very important for efficient routing. The problem of routing flow in a network of computers is extremely complex.

Routing protocols periodically probe the links to determine appropriate routes across the network. Routing protocols try to find the shortest, least cost, highest throughput, minimum delay and minimum overhead paths between a source and the destination. The common purpose of routing protocols is to compute the best route for data delivery. Routing protocols use metrics to evaluate what path will be the best for a packet to travel. A metric is a standard of measurement, such as path bandwidth, that is used by routing algorithms to determine the optimal path to a destination. To use or design an appropriate routing metric for a routing protocol, it is important to understand the characteristics of Wireless networks and identify what challenges will be faced. Therefore, to guarantee link quality, a good routing metric must take into account the metric characteristics to improve the performance of the routing protocol. A good routing metric should address the issues related to the key characteristics, such as, throughput, delay and overhead.

The routers in mesh networks are static, and thus dynamic topology changes are much less of a concern in such networks. As a consequence, the main design goal for routing protocols is shifted from maintaining connectivity between source and destination nodes to finding high-throughput paths between the nodes. Towards this goal, more sophisticated routing metrics than the hop-count metric need to be used to find paths that achieve high throughput, as protocols based on the hop-count metric often choose long links which tend to be lossy and give low throughput.

There are various kinds of routing metrics like hop count, ETX, ETT and so on. The concept of hop-count is quite simple where every link is counted as one unit and is independent of the quality of the link and hence it is the most widely used metric in routing protocols. The existence of error-free links is the implicit assumption made when hop count metric is chosen and hence while selecting the path for routing a packet it chooses the path with the smallest number of hops and ignores the quality of a link which ignores the possibility that a longer path might actually offer higher throughput.

ETX makes use of delivery ratios which are measured using dedicated link probe packets. Each node broadcasts link probes of a fixed size, at a fixed time period. Every node remembers the probes it receives during last interval which allows it to calculate the delivery ratio. In this paper we describe about implementation of ETX (Expected transmission count) metric in AODV (Ad hoc On-Demand Distance Vector) routing protocol. Since Ns-2 is a widely used tool to simulate the behaviour of wired and wireless networks we choose NS-2 as the network simulator to evaluate the performance of ETX metric with AODV routing protocol.

Rest of the paper is organized as follows: Section 2 describes the related work about AODV and ETX. Section 3 firstly explains why minimum hop-count often finds routes with significantly less throughput than the best available and then it presents the design, implementation, and evaluation of the ETX metric. Finally, it describes a set of detailed design changes to the AODV protocols (to which ETX is an extension), that enable them to more accurately choose routes with the best metric. Section 4 shows the results displayed after evaluating ETX metric by making use of X-graphs and execution of AWK scripts, and Section 5 concludes the paper.

II. RELATED WORK

In this section, we give an overview of various research works that has already been carried out in AODV and ETX. These works have helped us in implementing ETX metric in AODV.

In order to successfully implement ETX in AODV we need to first understand the working and behaviour of AODV [6] protocol. The Ad hoc On-Demand Distance Vector (AODV) algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network and to enable operation in AODV, Various message formats defined such are Route Requests (RREQs), Route Replies (RREPs), and Route Errors (RERRs).

Now to implement ETX in AODV, an extra packet type is required to sense the link quality between the source and destination. Thus, the widespread ETX metric [3] is calculated by sending probe packets to neighbours and calculating the loss ratio of the probe packets. The ETX is used as an indicator for the congestion level and the collision probability.

To implement ETX in any of the protocol researchers [5] tried to understand the meaning and complete definition of ETX. And then they came up with an ETX formula that can easily be applied and implemented for any of the protocol. Researchers defined ETX as Expected transmission count (ETX) is a metric that finds high throughput paths on multi-hop wireless networks incorporating the effects of link loss ratios and interference among the Successive links of a path.

Research has further been carried out [9] to show that ETX metric performs better than hop count metric.

Minimum hop-count metric regardless of large differences in throughput, chooses different paths of same minimum length. This metric also account to issues like interference between successive hops among multi-hop paths. ETX metric provides better improvement for paths with two or more hops, suggesting that transmission count offers increased benefit as networks grows larger and paths become longer. Research has been done on various steps [7] to implement new protocol in ns2.A detailed description on various procedures and files to be included in ns2 was proposed by the researchers.

III. PROPOSED WORK

In this section we describe the plug-in of ETX as a routing metric in AODV routing protocol for wireless mesh networks. ETX metric uses both MAC layer and network layer features like number of transmissions from MAC and based on ETX routing will happen at the network layer. The ETX in AODV proves to be an appealing cost metric because minimizing the total no of transmissions and retransmissions maximizes the throughput of an individual link and then overall network. We shall discuss the modifications to be done for some of the files in NS-2 to include ETX metric in AODV. We also present the changes to be made to AODV protocol to calculate the value of ETX which is used while routing the packets.

The AODV algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network. AODV allows mobile nodes to respond to link breakages and changes in network topology in a timely manner. And on the other hand, the ETX measures MAC transmissions and retransmissions to recover from frame losses.ETX of the wireless link is the estimated average number of transmissions of data frames and ACK frames necessary for the successful transmission of the packet. Alternatively, ETX of the link can also be defined as inverse of the probability of successful packet delivery or link reliability. Using ETX in AODV is advantageous because once the ETX value is known data packets can be transmitted and the calculated ETX will be used by the packets to choose best path to travel from its source to destination. Hence ETX does produce higher throughput than other routing metrics. Implementing ETX in AODV has shown better results with respect to some of the performance parameters than AODV alone.

To begin with the implementation the files already present in NS-2 are to be changed according to the files presented in [1]. The detailed description of the modifications shall be discussed in the next section. To reflect the changes mentioned in the following section we need to understand the dependencies that exist between different files in AODV and then configure NS-2 to analyse the results.

A. *Changes to be made to AODV to calculate ETX*

No more than 3 levels of headings should be used. All headings must be in 10pt font. Every word in a heading must be capitalized except for short minor words as listed in Section III-B.

1) Aodv_rtable.cc: AODV is a routing protocol, and it deals with route table management. Route table information must be kept even for short-lived routes, such as are created to temporarily store reverse paths towards nodes originating RREQs. The different fields used by AODV with each route table entry are Destination IP Address, Destination Sequence Number, Valid Destination Sequence Number flag, Other state and routing flags (e.g., valid, invalid, repairable, being repaired), Network Interface, Hop Count (number of hops needed to reach destination) Next Hop, List of Precursors, Lifetime (expiration or deletion time of the route) In order to include the value of ETX while routing another field named ETX should be added to the above mentioned fields.

2) *Aodv.cc:* In the TCL script, when the user configures AODV as a routing protocol by using the command " $ns node-config -adhocRouting AODV" the pointer moves to the "start" and this "start" moves the pointer to the Command function of AODV protocol. In the Command function, the user can find three extra timers in the "start". The first timer is used for sending ETX probe packets, the second timer handles the probe window timer and the third timer is used to manage the ETX probe packets.

When the timer for sending ETX probes is set an appropriate interval of Probe Packets is defined to schedule the packets. The node receiving the packet will check for different packets types and calls the respective receive mechanisms function.

On receiving an ETX probe packet the forward delivery ratio of a link is calculated using the formula

$$Forward\ delivery\ ratio = \frac{\text{probes count}}{PROBE\_WINDOW}$$

When the timer for handling the probe window timer is set an interval for Probe Window is defined to handle the window of the probe packets. The reverse delivery ratio is calculated for the number of probe packets received by a node from each neighbours during the last interval and then the timer is rescheduled.

On receiving an ETX probe packet the reverse delivery ratio of a link is calculated using the formula

$$\text{Reverse } \textit{delivery ratio} = \frac{\text{probes neighbors[neighbor]}}{PROBE\_WINDOW}$$

Finally the timer for managing ETX probes is set to some interval which removes all the old probe packets i.e. the packets that have expired.

Routing table Management: The routes chosen for routing the packets should consider the ETX value while updating the routing table in order to keep the latest information regarding the link quality. Whenever the route is down the ETX value is set to INFINITY (which is a very high value) which indicates the absence of a link.

Packet Reception Management: When a node receives a packet of type REQUEST, it firstly creates an entry for reverse route and calculates the value of ETX. Once the ETX value is known if we have a fresher sequence number or if we have a better link for the same sequence number then the routing table entry is updated with the new link quality as indicated by the ETX value. After taking care of the reverse route the receiving node now checks if it can send a route reply, if the receiving node itself is the destination it sends a reply with zero ETX value else if it is not the destination, but it has a fresh enough route then it sends a reply with the appropriate ETX value otherwise it simply forwards the route request.

When a node receives a packet of type REPLY, it adds a forward route table entry if a newer route is found to be better by comparing the ETX values of the newer and the older routes and updates the routing table entry. If the REPLY packet is destined for the receiving node then discard the packet else forward the route reply using the ETX value if the route is UP.

Packet Transmission Management: A node disseminates a RREQ when it determines that it needs a route to a destination and does not have one available. This can happen if the destination is previously unknown to the node or if a previously valid route to the destination expires or is marked as invalid. It fills out the RREQ packet and sets the ETX field to zero and sends the REQUEST messages. The first time a source node broadcasts a RREQ, it waits for a fixed interval of time for the reception of a RREP. If a RREP is not received within that time, the source node sends a new RREQ.

A node generates a RREP if either, it is itself the destination, or it has an active route to the destination where the destination sequence number in the node's existing route table entry for the destination is valid and greater than or equal to the Destination Sequence Number of the RREQ and also the ETX value in the node's existing route table entry is better the ETX vale of the RREQ packet. Once created, the RREP is sent towards the originator of the RREQ, as indicated by the route table entry for that originator. As the RREP is forwarded back towards the node which originated the RREQ message, the Hop Count field is incremented by one at each hop and the ETX of the route is maintained. Thus, when the RREP reaches the originator, the Hop Count represents the distance, in hops, and ETX represents the link conditions of the route from the destination to the originator.

The expected transmission count (ETX) metric which is based on the expected number of transmissions required to send a unicast packet over a link, including retransmissions. To calculate ETX, each node measures the probability that a packet successfully reaches the receiver, denoted as d_f, and the probability that an ACK is successfully received by the sender, denoted as d_r. The ETX value of the link is given by

$$ETX = \frac{1}{d_f \times d_r}$$

The AODV routing algorithm then selects the path with the least sum of ETX values of its constituent links. To measure d_f and d_r, each node broadcasts a probe packet every second. Each such probe contains the number of probes the node received from each of its neighbours in the last probe interval. Since the 802.11 MAC layer protocol does not retransmit broadcast packets, nodes use this information to estimate the forward and reverse delivery probabilities.

3) *Aodv_packet.h:* Here all kinds of packets used in AODV is defined. Since ETX is calculated by looking for the number of transmissions and retransmissions of the probe packets, we need to include an extra packet type. This packet type is probe packet. A new packet format named PROTOCOLETXTYPE_PROBE is defined by using a header macro for probe types. Another field named etx is defined and included while calculating the size of the structure defining the header of the request and reply type. Thus, a new structure to hold the probe packet information is defined as follows:

```
struct hdr_protocoletx_probe {
```

```
Packet Type
Source IP Address
Broadcast ID
Number of neighbours from which probes
        have been received
Their addresses
Number of the probes received
Timestamp when it was sent
size= sizeof(hdr_protocoletx_probe);
Return size
}
```

This probe packet type structure defined must be included while calculating the header space reservation which affects the packet header class defined for AODV routing protocol as shown below:

```
static class AODVETXHeaderClass:
        public PacketHeaderClass {
        AODVETXHeaderClass ():
        PacketHeaderClass   "PacketHeaderAODVETX",
size of (hdr_all_aodvetx)) {
        bind_offset (&hdr_aodvetx:: offset_;
        bind ();
}
```

As we know packets are used to exchange information between objects in the simulation, and our aim is to add our new struct hdr_protoname_pkt to them.

Doing so our control packets will be able to be sent and received by nodes in the simulation. And hence probe packets are an extension to the already available types of control packets in AODV. The structure defined earlier defining the probe packet is now added to struct hdr_protoname_pkt which is used to bind our packet header to Tcl interface.

An extra probe packet is being used to determine the link quality and thus this packet type should be added to the function named format_aodv () defined within the file " ns-allinone-2.34\ns-2.34\trace\cmu-trace\.cc".

IV. RESULT ANALYSIS

In this section, we present simulation results comparing the performance of AODV-ETX with AODV under different performance parameters.

B. *Simulation setup*

1) Scenario: NS 2.34 simulator is used for the simulation study. The model parameters that have been used in the following experiments are summarized in Table I.

TABLE I
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Sl. No	Parameter	Values
1.	Simulator	NS-2.34
2.	Routing protocol	AODV, AODV-ETX
3.	Channel	wireless
4.	Simulation time	45 seconds
5.	Number of nodes	150
6.	Bandwidth	1Mbps
7.	Traffic Type	FTP
8.	Packet Size	512 bytes

2) Evaluation: The following performance parameters are used to evaluate the protocol:

Average End to End delay: This metric represents average end- to-end delay and indicates how long it took for a packet to travel from the source to the application layer of the destination. It includes all possible delay caused by buffering during route discovery latency, transmission delays at the MAC, queuing at interface queue, and propagation and transfer time. It is calculated using the formula:

$$\text{AED} = \frac{\sum(\textit{time}\ \text{received - time sent})}{\textit{Total data packets received}}$$

Packet delivery ratio: This parameter is defined as the ratio of total number of packets successfully received by the destination nodes to the number of packets sent by the source nodes throughout the simulation which is given as:

$$\text{PDR} = \frac{\textit{Number of received packets}}{\textit{Number of sent packets}}$$

Normalized Routing Load: This parameter is defined as the ratio of total no of routing packets received to the total number of data packets received which is given as:

$$\text{NRL} = \frac{\sum(\text{Re}\textit{ceived routing packets})}{\sum(\text{Re}\textit{ceived data packets})}$$

C. Results

In this section we present the performance results in the form of numerically calculated values of Average end to end delay, packet delivery ratio, normalized routing overhead for both AODV and AODV-ETX. We also compare the performance of AODV-ETX versus AODV in the form of x-graph obtained after simulation which shall prove that performance of AODV-ETX is better than AODV alone.

1) Results Of Numerical Calculation

The numerical results obtained after the execution of AODV and AODV-ETX are given in the Table II:

TABLE III
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Sl. No	**Performance Parameter**	**AODV**	**AODV-ETX**
1.	Average End-End Delay	654.553ms	557.266ms
2.	Packet Delivery Ratio	43.4783	43.8483
3.	Normalized Routing Load	51.766	55.390

2) Results in the form of X-graphs

Average End to End delay:

We assume, in AODV only singular path exists between a source and destination node and hence during a link break the packet would not reach the destination due to unavailability of another path from source to destination. This packet increases the traffic which leads to the congestion in the network. In AODV-ETX when a link breaks the ETX value changes to INFINITY (some large value) which indicates the absence of the link. In such a case another path with the lowest ETX value is considered by the node to forward the packet. Thus an alternate path exists from source to destination during link failure.

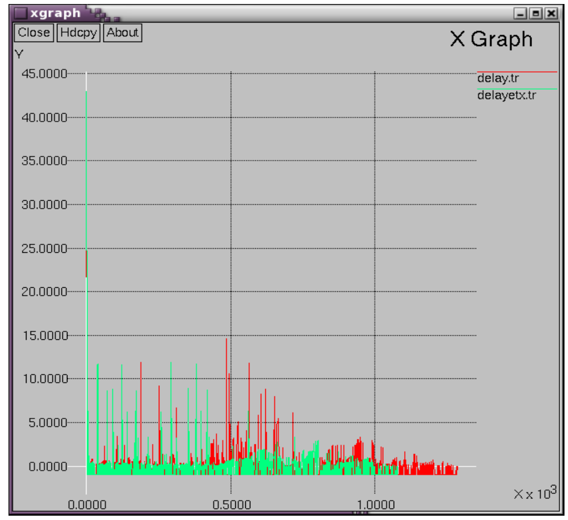

Fig 1. Comparison on the basis of End-End delay

Whenever a link is busy in case of AODV the sending node waits until the link gets free whereas in AODV-ETX another path is chosen to forward the packet instead of waiting for the link to get free. This extra time spent by the sender waiting for a free link increases the total delay.

Thus, AODV has an average delay of 654.553 ms to AODV-ETX's average delay of 557.266 ms which reveals that note that AODV-ETX has a better average delay than AODV. There is 17.46% improvement in average delay from AODV to AODV-ETX.

Packet delivery ratio:

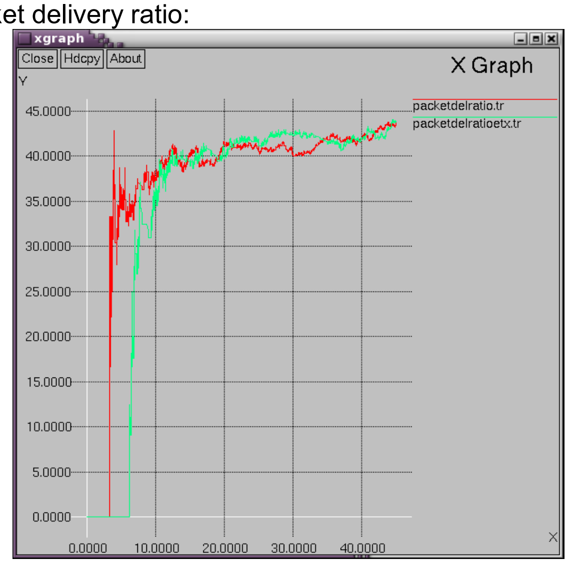

Fig 2. Comparison on the basis of Packet Delivery Ratio

The X-graph of packet delivery ratio versus the simulation time indicates that for most of the time the packet delivery ratio of AODV-ETX is higher than that of AODV and thus the average value of packet delivery ratio for the entire simulation time of AODV-ETX is higher than AODV. Thus, AODV has a packet delivery ratio of 43.4783 to AODV-ETX's packet delivery ratio of 43.8483. Thus there is 0.37 increase in packet delivery ratio from AODV to AODV-ETX.

Normalized routing overhead:

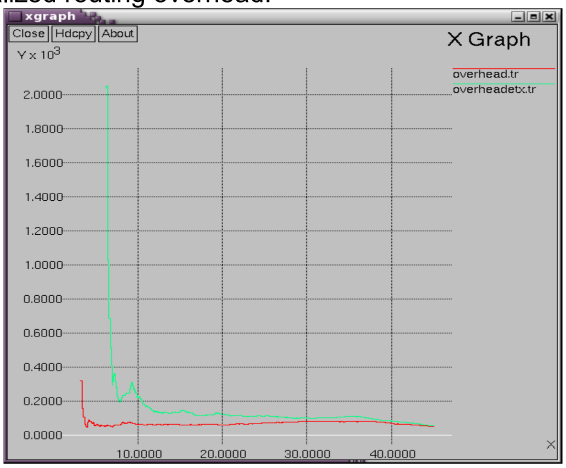

Fig 3. Comparison on the basis of Packet Delivery Ratio

The normalized routing load is number of routing packets sent per number of data packet received. From Fig 3 it can be observed that AODV-ETX has more routing overhead compared to AODV. In AODV-ETX extra probe packets are used to determine the link quality apart from RREQ, RREP packets as used in AODV. And thus the routing overhead for AODV-ETX is 7% higher than AODV.

V. CONCLUSION AND FUTURE SCOPE

This paper evaluates the performance of AODV and AODV-ETX using NS-2. Comparison was based on the packet delivery ratio, end-to-end delay and normalized routing load. We concluded that in the network with the simulation time of 45 seconds, AODV-ETX gives better performance as compared to AODV in terms of packet delivery fraction and end-end delay whereas AODV gives better performance in terms of routing overhead.

As future work, we intend to develop a module with ETX as a metric for routing in all the reactive protocols like DSR, TORA and release a patch that can be easily plugged-in to any of the reactive routing protocols.

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