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Enhancing Reliable Routing in Wireless Mesh Networks using Cross Layer Metrics

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***Abstract*–Wireless mesh networks have emerged as adaptable and low cost networks. Selfish behavior of mesh routers degrades performance. Expected Forwarded Counter (EFW) is a cross layer metric which combines link quality and forward reliability has been introduced to deal with the problem of selfish behavior in order to provide reliable routing. This paper proposes an enhancement to the EFW, by considering congestion incurred due to selecting only high quality paths. The performance of proposed metric is evaluated through simulation. Simulation results show that overall routing performance has been increased in terms of throughput and packet delivery ratio.**

Key Words– Wireless Mesh Networks, Cross Layer Metrics, Selfish behavior, ETX, EFW.

I. INTRODUCTION

Wireless Mesh Network (WMN) is a promising technology for the future generation wireless technologies [1]. The Mesh Networks are, self-configured, self-organized and easily adjustable to different traffic requirements and network changes. Routing is a challenge in Wireless Mesh Network due to unpredictable variations of the wireless environment.

Initially, to choose a path with the highest delivery rate in wireless mesh network, metrics that capture link quality [2], [3] have been introduced. But, most of these metrics are designed by imagining that each wireless mesh router contributes reliably in the forwarding process. While this assumption may not be valid in the presence of selfish routers which may get profit from not forwarding all traffic. Selfish users utilize the network resources for its own benefit, but unwilling to spend for others. Such selfish behavior reduces network delivery reliability [4]. Metrics like [5], [6] have been introduced to detect and exclude selfish nodes in a route to destination. These metrics focused more on selfish behavior of nodes and do not consider the quality of links, hence cannot select the best path from source to destination. Cross layer metrics [7] were used to consider both link quality and selfish behavior of a node in order to select a high performance path. This kind of solutions may cause only high quality links to get used and other links will get unused. This will make links to be congested seriously and in turn cause performance degradation. To provide a solution for the above discussed issue, in this paper, we propose anovel metric, which combines link quality and congestion information from MAC layer and forward reliability of nodes from routing layer.

The rest of this paper is structured as follows. *Section 2* discusses related work which includes ETX and EFW metrics explanation. *Section 3* illustrates proposed work. *Section 4* presents results obtained through simulating proposed metric in comparison with the ETX and EFW. Finally, we conclude in *Section 5*.

II. RELATED WORK

In recent years, several routing metrics have been proposed to choose routes with thehighest delivery rate in wireless mesh networks. All these metrics are used for the selection of reliable network paths, avoiding wireless links that prone to transmission errors. Some of these are discussed below.

A. ETX (Expected Transmission Counter)

S.J. De Couto et.al [8] introduced a routing metric ETX, which estimates the quality of wireless links. To symbolize the transmission reliability of a wireless link,a probabilistic model has been used by ETX. The ETX estimates the expected number of transmissions, including retransmissions, required to successfully deliver a unicast packet over a wireless link. ETX is computed based on loss probabilities in forward and reverse directions, since in wireless networks, according to IEEE 802.11 protocol, the destination node must acknowledge each received data frame.

Let (i,j) be a wireless link established between node and j then p_{ij} and p_{ji} indicate the packet loss probability of the wireless link (i,j) in forward and reverse directions respectively. The probability to deliver successfully on the wireless link (i,j) can therefore be computed as

$$p_{s,ij} = (1 - p_{ij})(1 - p_{ji}) \qquad (1)$$

Then, the expected number of transmissions required to successfully deliver a data packet, can be evaluated according to the expression [8].

$$\text{ETX} = \frac{1}{p_{s,ij}} = \frac{1}{(1 - p_{ij})(1 - p_{ji})} \qquad (2)$$

Thus ETX finds route with the highest probability of packet delivery. D. Johnson et.al [9]shows that ETX does not accurately estimate the delivery rate of the link, since it doesn't consider selfish behavior of nodes.

B. EFW (Expected Forwarded Counter)

To solve the problem caused by the selfish behavior of nodes, S. Paris et.al [10] introduced a metric that combine the link quality computed by the ETX metric with the forwarding probability of a relaying node j. Forward probability is computed as a function of dropping probability.

Let dropping probability of network node j at network layerbe $p_{d,ij}$ then $p_{f,ij}$ = $(1 - p_{d,ij})$ is its forwarding probability. The dropping probability of a node j is measured using both sending node and relaying node j, because a network node can selectively drop the traffic sent from its neighbors. The probability that a packet sent through a network node j will be successfully forwarded can be computed as

$$p_{fwd,ij} = p_{s,ij}(1 - p_{d,ij}) \qquad (3)$$

Then, the expected number of transmissions required to successfully forward the packet (Expected Forwarding Counter, EFW) can be computed as follows [11].

$$\text{EFW} = \frac{1}{p_{fwd,ij}} = \frac{1}{(1 - p_{ij})(1 - p_{ji})} \cdot \frac{1}{(1 - p_{d,ij})} \qquad (4)$$

The first part of the equation, which matches with the ETX metric, reflects the quality of the physical and MAC layers, whereas second part considers network layer reliability. Therefore, EFW is a cross-layer metric that prototypes both the physical environments of the wireless medium and the selfish behavior of the node with which the link has been established.

So EFW permits to select the highest delivery paths in the presence of selfish nodes in wireless mesh networks. Even though, EFW selects a high throughput path, it doesn't lead to select best end to end paths in a congested environment due to inaccurate link quality estimation technique of ETX in congested networks [12]. In congested networks, a packet dropped due to congestion also counted under link quality estimation.It doesn't differentiate between packets lost due tocongestion of link and link quality. So the link quality estimation is not accurate. Hence, a technique able to improve link quality estimation can be used in order to enhance routing performancein congested networks.

III. PROPOSED METRIC : CONGESTION AWARE EFW (CEFW)

This section discusses our proposed metric, the Congestion aware Expected Forwarded Counter (CEFW). The disadvantages of the existing solutions [13] for reliable routing in wireless mesh networks with selfish participants are:

- Solutions based on link quality allow nodesto use the only high quality links and cause them congested seriously. And at the same time other links will get unused.
- The link quality estimation techniques in above solutions consider retransmission of DATA occuronly due to link layer problem which will cause inaccurate estimation of link quality in congested networks.

To solve these issues we combine the following congestion aware and link quality estimation technique with the forward probability estimation technique of EFW metric in order to improve routing performance in case of congested networks.

The metric formed by combining like this is named as the Congestion aware EFW.

Congestion aware and Link Quality Estimation Technique

This technique is based on the retransmission mechanism employed in IEEE 802.11b, which is employed for lost unicast packets. This technique considers not only retransmission of DATA frames, but also retransmission of RTS frames.

- DATA retransmission occurs if an ACK is not received in response to DATA frame.
- RTS retransmission occurs if a CTS frame is not received in response to RTS (Request to Send) frame.

RTS used to check availability of the channel. If CTS (Clear to send) is not received in the specified time interval, we understand that channel is busy and retransmit RTS frame after some interval. In this way RTS retransmission gives information about congestion of the link.

After the RTS/CTS handshake DATA transfer will take place. IfACK is not received in response to DATA in specified time interval, then it is understood that packet lost due to link problems. So, retransmission of DATA gives information about link quality.

The above discussed retransmission mechanismat MAC layer is illustrated in the figure1.

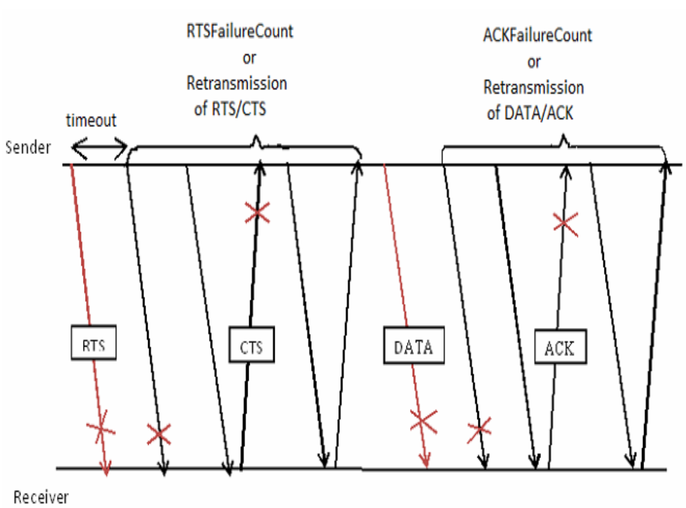

Figure1: Retransmission mechanism at the MAC Layer

This technique differentiates between packets lost due to congestion and link problems. Therefore, in designing the metric it is supposed that the number of retransmissions of RTS and Data frames for each successful transmission in MAC layer represents the quality of that link and also congestion of the cell.

The success rate of sending frames istherefore a good estimate of both the quality andcongestion of a link. Hence, we propose to use it as a metric for choosing the best quality links, as defined by those that require the least retransmissions.

The success rate of transmitting frames based on the average number of retransmissions which we call Frame Transmission Efficiency or FTE. The success rate of each link (FTE) isupdated when a node forwards a Data packet to itsneighbor and passes it up to the routing protocol.To represent a number of Data and RTS retransmission, we use IEEE802.11 MIB (Management InformationBase) variables[14] like ACKFailureCount and RTSFailuerCount respectively.

The k^{th} packet will send from Node S to Node D. The number of retransmission is denoted by Failure (k) and can be computed as:

Failure (k) = ACK Failure Count (k) + RTS Failure Count (k)

Thus FTE (k) between Node S and Node D is formulized as equation. It reflects the link quality and congestion situation of links [15].

$$\text{FTE (k)} = \frac{2}{Failure\,(k) + 2} \qquad (5)$$

We are using this frame transmission efficiency to represent link quality and congestion. It is MAC layer information. From routing layer we consider forward probability estimation. In cross layer fashion, we combine information from both MAC and Routing layer to obtain congestion aware EFW. It is computed as follows

$$\text{Congestion aware EFW (CEFW)} = \frac{2}{Failure\,(k) + 2} \cdot \frac{1}{(1 - p_{dij})} \qquad (6)$$

IV. SIMULATION RESULTS

This section discusses simulation results obtained by evaluating above discussed, routing metrics with NCTUns6.0 simulator. The simulation scenario employed has been discussed below

A. *Simulation scenario*

In this simulation, we considered a 5x5 square grid topology of 25 nodes with grid spaces of 200m. A grid topology has been chosen due to its facility to create a fully connected mesh network and possible to create a large variety of other topologies by switching on certain nodes. All nodes employ IEEE 802.11b MAC protocol. The wireless transmission range is 250m.

The propagation model is two way ground. OSPF (Open Shortest Path First) has been used as a routing protocol during simulation, since it is widely used for internet applications [16]. The Simulation time is 140 seconds. The network performance evaluated using CBR (Constant Bit Rate) traffic over UDP connections.

B. *Performance Evaluation*

To evaluate the performance of proposed metric in comparison with the existing metrics ETX and EFW, the following variables are analyzed.

*Throughput***:** The throughput is calculated dividing the total amount of data received by the time of simulation.

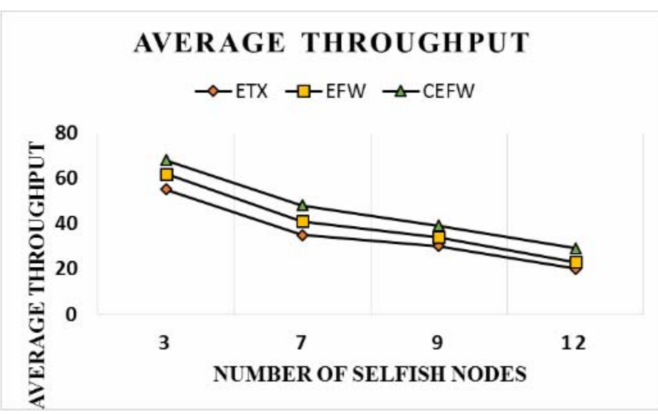

Figure 2: Average throughput for ETX, EFW and CEFW

From figure2, we can observe that the proposed metric has more throughput than the other routing metrics in wireless mesh networks. Since, the proposed metric handles congestion caused by selecting only high quality paths. By this we can understand that the proposed metric selects a better path in the presence of selfish nodes in comparison with other metrics.

Packet Delivery Ratio

It is calculated by the ratio of the number of delivered data packet to the number of packets sent.

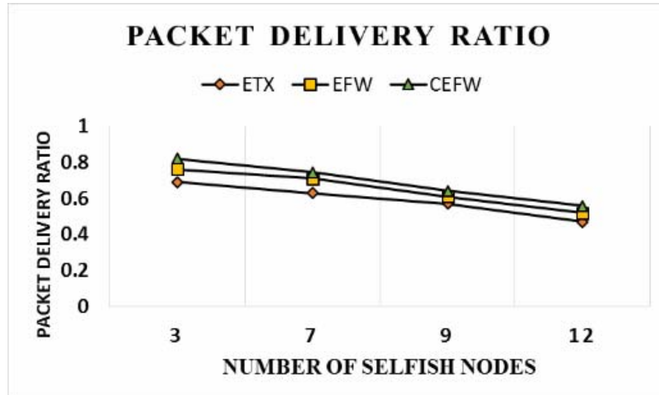

Figure 3: Packet Delivery Ratio of ETX, EFW and CEFW

From figure 3. It seems that congestion aware EFW has more packet delivery ratio when compared with other metrics. The Packet delivery ratio is more for CEFW because it selects the highest delivery path by avoiding selfish nodes and selecting high quality and less congested route to destination.

V. C ONCLUSION AND FUTURE WORK

In this paper, we introduced an enhancement to existing cross layer metric called Expected forward counter (EFW). In this metric we replaced link quality metric obtained from ETX metric with Frame Transfer Efficiency (FTE) metric which considers not only link quality but also congestion of the link. As the proposed metric in cross layer fashion combines MAC layer observations of link quality and congestion with routing layer observations of forward probability estimation, it gives better performance in comparison with the ETX and EFW metrics.

Simulation results show that routing performance of Open Shortest Path First routing protocol in terms of throughput, packet delivery ratiohas been improved in proposed metric.

The proposed metric can be combined with other routing protocols of wireless mesh network. Evaluating the performance of proposed metric CEFW using other routing protocols is our future work.

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