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Procedia Computer Science 19 (2013) 1108 – 1115

Procedia Computer Science

8th International Symposium on Intelligent Systems Techniques for Ad hoc and Wireless Sensor Networks (IST-AWSN)

Performance Evaluation of the IBETX Routing Metric over DSDV Routing Protocol in Wireless Ad hoc Networks

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Abstract

Wireless ad-hoc networks are characterized by a collection of wireless mobile nodes that dynamically form a temporary network without the use of any pre-defined network infrastructure or centralized administration. They have attributes such multi-hop wireless connectivity, continuously changing topology and easy deployment. The increasing demands that are made by users pose a challenge in the improvement of the quality of wireless ad-hoc networks. The performance of wireless ad-hoc networks depend on the efficiency of routing protocols, especially the routing metric operating within it. In this paper, the performance of the recently proposed routing metric Interference Bandwidth Adjusted Expected transmission count (IBETX) metric is compared with two prominent existing metrics, the Expected transmission count (ETX) and the Inverse Expected Transmission count (InvETX) over the Destination Sequenced Distance Vector (DSDV) routing protocol. The performance differentials are analysed using varying packet rates and node densities. From the simulations results, IBETX metric outperforms the ETX and InvETX metric because it implements the bandwidth sharing mechanism and makes use of the information available at the MAC layer. It can also be noted that it is very sensitive to data traffic rate. It performs well in low and medium node densities.

Selection and peer-review under responsibility of Elhadi M. Shakshuki

Keywords: Multi-hop wireless networks; routing link metric; DSDV; IBETX; InvETX; ETX

1. Introduction and related work

Ad-hoc networks consist of wireless nodes that are not in the transmission range of each other. Intermediate nodes act as routers to receive and send routing and data packets to the nodes within their

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Selection and peer-review under responsibility of Elhadi M. Shakshuki
doi:10.1016/j.procs.2013.06.156

transmission range. In this network, messages are relayed or routed over multiple wireless hops to reach their destination through the utilization routing protocol. The routing protocol is responsible for the control of the formation and configuration of the topology of the network, and in the selection of the best path from source to destination. The strength of a routing protocol depends on the efficiency of the link metric that operates on it. The link metric is essentially a value assigned to each route or path and is used by the routing algorithm to select one or more routes, out of a subset of routes discovered by the routing protocol. These values generally reflect the cost of using a particular route with respect to some optimization objective (minimize delay, maximize probability of data delivery, maximize path or network throughput or minimize energy consumption). It plays an essential role in achieving the desired performance of the underlying network by making the routing protocol: fast enough to adopt topological changes, light weight to use the resources of nodes minimally and make the network intelligent in selecting the fastest path from source to destination among the available paths enabling nodes to have comprehensive knowledge regarding the topology of the network.

Being the most popular link metric, minimum hop count is the traditional routing metric used in most of the common routing protocols such as AODV [1] and DSDV[2], It finds paths with the least or the shortest number of hops. However, new paths must rapidly be found in situations where paths with minimum quality could not be found in due time as a result of high mobility. Moreover, in some wireless ad-hoc networks (static networks or mesh networks) where mobility is not an issue it may choose paths with low throughput and poor medium utilization. To overcome the limitations of the minimum hop count various link quality metrics have been proposed in literature. One of the most popular work in this domain was done in [3, 4], the authors proposed the Expected Transmission Count (ETX) metric that predicts the average number of data frame and ACK frame transmissions necessary to successfully deliver a packet over a wireless link. ETX selects routes with better delivery ratios as compared to the hop count, thus increasing the throughput. According to the original ETX, it is inversely proportional to the expected probability that a transmission is successfully received and acknowledged. Therefore, the inverse ETX (InvETX) metric [5] is defined as the probability of successful packet transmission. Both only capture link loss ratio ignoring the interference experienced by the links which has a significant impact on the link quality and the data rate at which packets are transmitted over each link. They do not consider differences in transmission rate. As the transmission rate of probe packets is typically low, they do not accurately reflect the loss rate of actual traffic. An important factor often neglected in most of existing metrics is that routing in multi-hop wireless networks can significantly be improved by cross-layering with lower layers. The motivation behind this work is that a better understanding of the relative merits of the Interference Bandwidth adjusted ETX (IBETX) metric will serve as a cornerstone for development of more effective one.

The rest of this paper is organized as follows. In Section 2, a detailed description of the Interference Bandwidth adjusted ETX (IBETX) link metric [6, 7] is presented. This lays a foundation for much of the context of the performance study. Section 3 describes the different performance metrics used to evaluate the different metrics. This is followed by simulations results and their interpretations in Section 4. Conclusions are drawn in Section 5, as well as recommendations for future work.

2. Interference and Bandwidth adjusted Expected Transmission count (IBETX) metric

Simple path selection based on the ETX metric often may lead to poor performance due to the fact that it does not consider differences in the transmission rates of the links. As it does not consider the load of the link, it will route through heavily loaded nodes leading to unbalanced resource usage. Better paths can be obtained by characterizing the actual quality of wireless link, in [6, 7] the authors propose the IBETX metric. It is a threefold metric. It firstly calculates the Expected Link Delivery (ELD), $d_{\exp}$ that avoids the overhead as generated by the ETX and bypasses congested regions in the network; this part of the IBETX metric finds paths or routes with a lower number of retransmissions that may be used for onward delivery of data packets. In wireless networks, slow links receive more time to transmit compared to the fast ones, therefore it provides the nodes with the information of nominal bit rates and makes them to compute the Expected Link Bandwidth (ELB), $b_{\exp}$ of all the wireless links in the same contention domain using a cross-layer approach. Finally, IBETX overcomes long path penalization of ETX by calculating the interference referred to as Expected Link Interference (ELI), $I_{\exp}$ .The IBETX metric is defined as follows:

$$IBETX = \frac{d_{\exp}}{b_{\exp}} * I_{\exp} \tag{1}$$

For a bidirectional wireless link (m,n) the expected link delivery $d_{\exp}$ is obtained by

$$d_{\exp} = d_f * d_r \tag{2}$$

where d_f is the forward delivery ratio which is the measured probability that a data packet successfully arrives at the receiver and d_r is the reverse delivery ratio which is the probability that the acknowledgment packet is successfully transmitted. The delivery ratios are measured using link layer broadcast probes, which are not acknowledged at the 802.11 Medium Access Control (MAC) layer. Each node broadcasts a probe packet of 134 bytes every second and also remembers the number of probe packets received from each neighbouring node over the last 10 seconds. Once this information is obtained, the expected link delivery for all the wireless links from that node to its neighbours is calculated. The expected link Bandwidth $b_{\exp}$ captures the bandwidth sharing mechanism of 802.11 Distributed Coordination Function (DCF); it also considers the accurate throughput reduction of the faster links as a result of slower ones. Moreover, $b_{\exp}$ also takes into account the longer paths that are ignored by the ETX and ETX-based metrics. For a link (m,n) , the expected link bandwidth is given by:

$$b_{\exp}(m,n) = \frac{1}{\sum_{i \in P \cap NP} \frac{1}{r_i}} \tag{3}$$

In the above expression, *P* is the source destination path or route and *NP* is the non-source destination path, r_i is the nominal bit rate of the i^{th} link in the domain $P \cap NP$ which is the set of links in path *P* that contend with the link (m,n) . Since the probes used to calculate the delivery ratio are very small in size, they are successfully received even in a congested network, thus depicting the wrong image of link qualities. For example, if a link has only capacity to carry probe packets, it pretends that the congested link is a link with better quality because of its high delivery ratios. In fact, it is not able to carry data packets [8]. Therefore a mechanism is incorporated to calculate the interference in the IBETX metric and which is defined as ELI. It is an expected value calculated by all the nodes on the same source-destination path. The 802.11's basic MAC is the Distributed Coordination Function (DCF) which besides enabling the nodes to sense the link before sending data, also avoids collisions by employing virtual carrier sensing. DCF uses Request-To-Send (RTS) and Clear-To-Send (CTS) control packets for unicast data transmission to a neighbouring node and consequently sets the Network Allocation Vector (NAV), i.e.,

$NAV = \tau_{RTS} + \tau_{CTS}$ stores the channel reservation information to avoid the hidden terminal problem. Using the cross-layer approach, DCF periodically probes the MAC to find the time period for which the link is busy, τ_{busy}. The interference that a node *m* has to suffer is expressed as:

$$i_m = \frac{\tau_{busy}}{\tau_t} \tag{4}$$

where τ_{busy} is the duration for which the medium remains busy; in the case of receiving packets it is R_x state (or communication is going-on with other nodes) and the *NAV* pending. In the interference expression for node *m*, τ_t is the total window time. If node *n* is at the transmitting end, the τ_{busy} value is given by $\tau_{R_x} + \tau_{T_x} + \tau_{RTS} + \tau_{CTS}$. Thus, the interferences for the sending node *n* and the receiving node *m* are given as

$$i_m = \frac{\tau_{R_x} + \tau_{RTS} + \tau_{CTS}}{\tau_t} \tag{5}$$

$$i_n = \frac{\tau_{R_x} + \tau_{T_x} + \tau_{RTS} + \tau_{CTS}}{\tau_t} \tag{6}$$

The link (m,n) formed by nodes *m* and *n* will suffer from interference, i_{mn} that is the maximum of the interferences calculated in equations (5) and (6).

$$i_{mn} = Max(i_m, i_n) \tag{7}$$

The receiving node *m* saves the information of interference computed by equation (5) and sending node, by equation (6). The expected interference of the link (m,n) is then evaluated as:

$$I_{\exp}(m,n) = \frac{i_{mn}}{1 + i_{mn}} \tag{8}$$

Since wireless medium are shared, they have the problem of interference due to contention. This causes packets to be lost due to collisions, and consequently reduces the bandwidth of links. Therefore, $I_{\exp}$ is added to handle the inter-flow interference among contending nodes. The weight of a path is defined as the summation of IBETX's of all links along the path. Therefore, the IBETX path metric for a path *p* becomes:

$$IBETX(p) = \sum_{l \in p} IBETX_l \tag{9}$$

Then the routing metric for the best route or path P_{best} from source to destination is the minimum value of all available *P's*. As given below:

$$P_{best} = \min\left(IBETX(P_1), IBETX(P_2), ..., IBETX(P_n)\right) \tag{10}$$

3. Performance metrics

Four important metrics are considered. These include:

(i)Throughput: which is defined as the total amount of data a receiver receives from the sender divided by the time it takes for receiver to get the last packet. It is actually the measure of how fast we can send packets through the network.
(ii) Normalized Routing Load (NRL): which is the number of routing packets transmitted by a routing protocol (DSDV routing protocol in this study) for a single packet to be delivered successfully at the destination. It describes how many routing packets for route discovery and route maintenance need to be sent in order to propagate the data packets.
(iii) Average end-to-end delay: indicates how long it takes for a packet to travel from the source to the application layer of the destination. It includes all possible delays caused by buffering during route discovery, retransmission delays at the MAC, queuing delay at the interface, propagation and transfer times.
(iv)Packet delivery ratio (PDR): is the fraction of data packets delivered to the destinations to those generated by the Constant Bit Rate (CBR) sources.

4. Simulations and results

This section provides the details concerning the simulation environment and the results. The entire simulations were carried out using NS-2.34 network simulator [9] which is a discrete event driven simulator widely used in the networking research community. It is open source and includes the capability of creating custom applications and protocols as well as modifying several parameters at different layers. We are dealing with static networks where proactive protocols work at their best because of getting the picture of the whole topology and independent of the data generation. Among the widely used proactive protocols, we decided to use DSDV because ETX and InvETX metrics have been implemented in it. On the other hand, along with periodic updates, DSDV also uses trigger updates. The trigger updates help DSDV to reduce routing overhead that raises throughput. The nominal radio range and the channel capacity of each node are set to 2*50 m* and *2 Mbps* respectively. The window used for link probe packets is chosen to be of size *10 s*. At the MAC layer, the simulator uses a DCF that is compliant with the IEEE 802.11 standard. Each simulation runs for five different topologies for *900 s* each and each data point represents an average of five runs.

4.1 traffic load analysis

To examine the performance of the discussed link quality metrics under different network loads, the traffic rate is varied from 1 to 10 packets per second. In the area of $1000 \times 1000\ m^2$, 50 nodes are placed randomly to form a static network.CBR traffic is randomly generated by 30 source-destination pairs with packet size of *512 bytes*.

Considering the ETX and the InvETX approach, the detection of the link data delivery ratio may not be truly accurate due to the way they broadcast small probe packets to detect the data delivery ratio, and considering that probe packets are sent at a lower data rate. This estimation may not reflect the real packet loss ratio, because actual packets are usually larger and sent at higher data rates. Therefore, taking the bandwidth of all links in the same contention domain into account gives more accurate information about the link status as compared to simple considering probability of successful transmission. IBETX tackles this issue by implementing a bandwidth sharing mechanism of 802.11 DCF. Consequently, it achieves increased throughput as compared to ETX and InvETX, as observed from Figure 2.

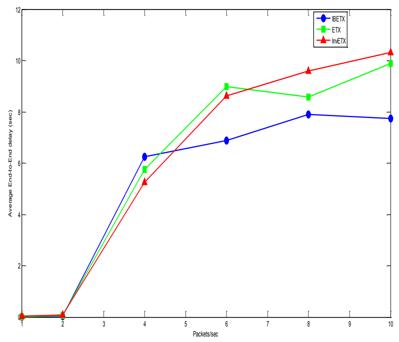

Figure 1: Average end-to-end delay versus packet rate

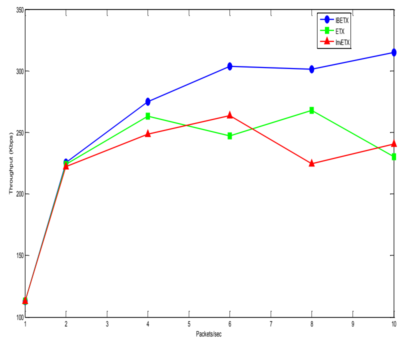

Figure 2: throughput versus packet rate

As packet rate increases it can be seen From figure 1 that the average end-to-end delay for all the metrics also increases, but is less for the IBETX and InvETX metrics because they are taking the product of forward and reverse delivery rates of a link and not the reciprocal as ETX does. Furthermore to accurately estimate the medium occupation, using cross-layered approach, IBETX through ELI periodically probes the MAC-layer. In the MAC broadcast probes, all the nodes in the network piggyback their interferences for the last 10 seconds, hence, IBETX avoids extra routing overhead (Figure 3) and reduces the average end-to-end delay.

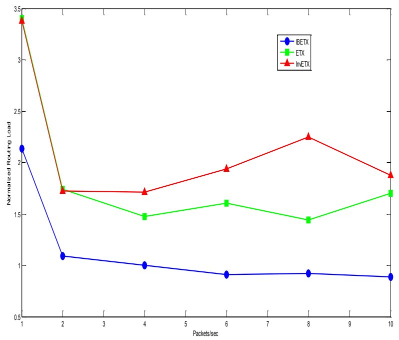

Figure 3: Normalized routing load versus packet rate

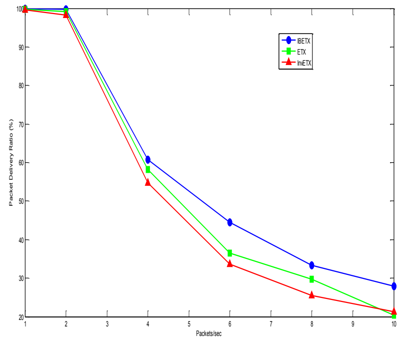

Figure 4: Packet delivery ratio versus packet rate

There is a strong relation between the normalized routing load and the packet rate, The NRL decreases when the packet rate increases as shown in Figure 3. As data or packet rates are higher and buffers are full, probe packets having priority over data, are inserted in the front of the buffers and subsequently data is pushed outside and dropped, leading to network congestion. The packet delivery ratio drastically decreases when the packet rate become high. But again IBETX metric outperforms ETX and InvETX in terms of packet delivery rate.

4.2 Scalability analysis

To evaluate the performance of the metrics under different node densities, simulations are run for 10, 30, 50, 70, 90 and 100 nodes. For 10 nodes, the number of sources is 4, for 30 these are 12, and each incremental of 20 nodes 8 sources are added. For 100 nodes, there are 40 sources. The packet rate is set to 4 packets / s.

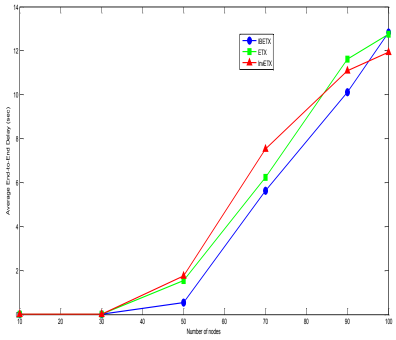

Figure 5: Average end-to-end delay versus number of nodes

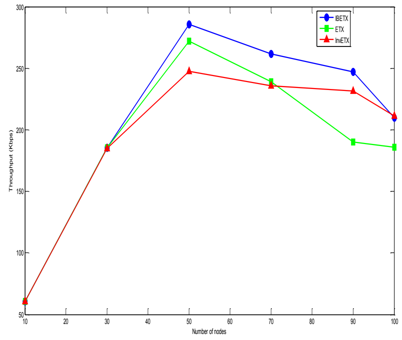

Figure 6: Throughput versus number of nodes

As the number of nodes increases, there are more contentions and flows going on. Because the ETX and InvETX metrics do not implement any method to take into account the inter-flow interference and the bandwidth sharing mechanism, they have low throughput, high average end-to end delay and high NRL (Figure 5, 6, 7 and 8) as compared to the IBETX metric. It can be also seen that the performance metrics of all discussed link metrics suffer as the number of nodes increases, because all the mentioned link metrics employ active probing in order to estimate the quality of the link. This mechanism causes an excessive overhead (figure 7).

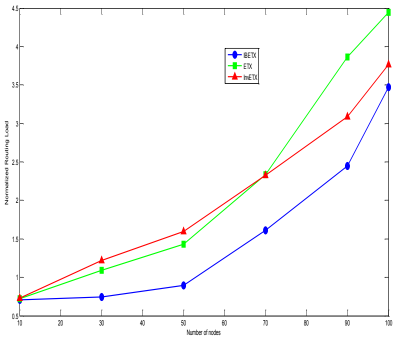

Figure 7: Normalized routing load versus number of nodes

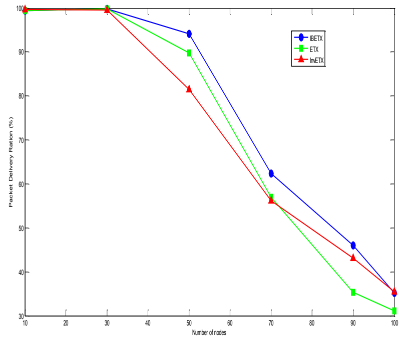

Figure 8: Packet delivery ratio versus number of nodes

5. Conclusion

In this paper, a link quality metric that was recently proposed for wireless Multi-hop networks, which overcomes the performance limitations in ETX due to its limited awareness of the MAC layer was first presented. ELD was able to find high throughput paths more efficiently than ETX by avoiding the overhead due to the computational complexities. ELB was able to find quality links from all active links in the same contention domain. ELI together with the ELB removed the deficiency in ETX and InvETX by ignoring longer paths while selecting quality links, even though the longer paths may provide higher throughputs. Simulations were performed and presented to evaluate the performance of the new link quality metric over DSDV routing protocol for different packet rates and network sizes, it was observed that the IBETX metric outperforms ETX and invETX in terms of throughput, average end-to-end delay, NRL and PDR. It was also shown to be sensitive to the packet rate. Since in DSDV, each node stores the entire information of the network topology and tries its best to record every destination it learns from neighbours, which leads to a higher success ratio in the route discovery process, however, its overhead increased rapidly along with the number of nodes, Therefore, it might no scale in large or high density networks. For future work, the extension of the IBETX metric over other routing protocols (AODV and OLSR) will be considered, and an enhanced IBETX based on physical layer parameters such as the Signal-to Noise Ratio (SNR) will be taken into account as well. This can shed further light on the impact of physical layer on optimal routing decisions and the support for multi-channel networks [10, 11, 12].

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