What is Wrong with Broadcast Probing Based ETX Estimation for Wireless Links?

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ABSTRACT

ETX (Expected Transmission Count) is shown to be the best link metric in terms of higher throughput for wireless multi-hop network with stationary-nodes having single radio. Some recent work, however, shows that ETX may exhibit high sensitivity to interference and a single TCP flow can increase the metric value by 10000% [1]. Such a change indicates that routing protocols, based on ETX, might be playing with random numbers without bringing any significant benefits of considering link quality. It is suggested that broadcast-based estimation of ETX could be the major cause of sensitivity as other metrics based on unicast probing method did not show similar performance degradation [1]. Several proposals came forward so far focusing on better estimation techniques of ETX metric mostly using unicast probing combined with cross-layer information; however, we have not seen any investigation study as to why does broadcast-based method result in inaccurate estimation of ETX. This paper presents preliminary results of an investigation study about the sensitivity of ETX estimation based on broadcast probing and compare it with the one based on unicast probing. It is work-in-progress.

1. INTRODUCTION

In a wireless multi-hop network with stationary-nodes having single radio, ETX (Expected Transmission Count) is shown to be the best link metric in terms of higher throughput [2, 3]. ETX is a link quality indicator and shows the expected number of transmission attempts over a wireless link in order to achieve successful delivery of the packet [2]. A weak wireless link would require many more attempts, i.e., a larger ETX value, than a strong link. A detailed comparison of different routing metrics developed for multi-hop wireless networks is done in [3]. Link metrics studied by [3] include ETX [2], RTT (Round Trip Time), and PktPair (Packet Pair delay) [3], and their performance is compared with the minimum hop-count routing. ETX achieved the best throughput in the experiments with static node scenario [3].

Some recent work, however, show that ETX may exhibit lower throughput than that observed with minimum hop-count routing and RTT, for operating conditions when probing overhead becomes significant than the relative path losses of alternative paths [4]. It is also shown that ETT (Expected Transmission Time), a modification of ETX for nodes with multiple radios, is highly sensitive to interference and a single TCP flow can increase the metric value by 10000% for many links in the neighborhood [1]. Such a change indicates that routing protocols, based on ETT or ETX, might be playing with random numbers without bringing any significant benefits of considering link quality.

Das et al. suggested that broadcast-based estimation of ETX or ETT could be the major cause of sensitivity as other metrics based on unicast probing method, i.e., bandwidth, did not show similar performance degradation [1]. Several proposals came forward so far focusing on better estimation techniques of ETX metric mostly using unicast probing combined with cross-layer information [5, 6]. Although, we have not seen any investigation study as to why does broadcast-based method result in inaccurate estimation of ETX. We also remark that unicast probing method generates a lot more probing packets at network layer than broadcast probing.

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The paper is organized as follows: Section 2 discusses the issues with ETX link metric in general reported by the research community, Section 3 discusses the issue of broadcast versus unicast probing in detail, Section 4 discusses details about our mesh testbed and experiment setup and finally Section 5 outlines our findings. Section 6 concludes the paper.

2. RELATED WORK

ETX is found to outperform minimum hop-count metric in [2] and [3] in terms of throughput. Draves et al. performed independent assessment of different routing metric for WMN using an indoor testbed and showed that ETX yields the highest throughput, compared with minimum hop-count, RTT, and PktPair, in static scenario. In mobile scenario, however, minimum hop-count is showed to have higher throughput than ETX because the reaction time of ETX is much slower than the changes in the network topology [3].

Although, ETX is theoretically the best throughput metric, but estimation of link ETX is seemed to be a major cause of performance anomalies. Das et al. performed comprehensive measurements over 2 mesh testbeds to study the variability and sensitivity of routing metrics [1]. They observed significant variation in ETX estimates. Although, they found correlation between link quality and variability but some good links also showed higher variability. ETX is also found to be highly sensitive of time-of-the-day, i.e., changes in environment, and also to the background traffic. Link metric based on broadcast probing showed to be increased by 10000% for 30% of the links in an experiment by just a single TCP flow. In this case the estimated values are basically meaningless and route selection is just done with random values. Das et al. concludes that since link metrics based on unicast probing method, e.g., bandwidth, are not affected by the background traffic, the sensitivity of ETT or ETX is due to the broadcast probing method.

Alternative metric estimation techniques are also proposed in literature which mostly relies on cross-layer information combined with unicast probing. Using measurements of link-layer re-transmissions for data packets and unicast probes, when links are inactive, for ETX estimation is the key idea used in [6] and [5]. Passive monitoring of link-layer re-transmissions is a reasonable idea but it has to be accompanied with unicast probing to cover the inactive links. Profiling SNR (Signal to Noise Ratio) versus packet delivery is used in [7] to indirectly measure link strength or ETX metric. However, experiment results show that the relationship between SNR and packet delivery is not clearly characterizable due to variability of the environment and low-cost components used in wireless cards [8].

3. BROADCAST VS. UNICAST PROBING

ETX is the expected number of transmission required to achieve successful delivery of a packet on a wireless link. If \( p_o \) is the probability of successful packet delivery of an outgoing link from a node to its neighbor and \( p_i \) is the probability in reverse direction, i.e., incoming link from the same neighbor. ETX can be written as \( \text{ETX} = \frac{1}{p_o p_i} \) [2]. To calculate ETX in real networks, each node broadcasts periodic probes to its neighbors. The probability \( p_i \) is estimated as the ratio between number of received broadcasts from the neighbor and total number of probes which should be transmitted in a given interval. The probability \( p_o \) is calculated by the neighbor node which then embed the information in its probe packets.

In case of unicast probing for ETX estimation, there could be two alternatives to estimate ETX. One, used in our analysis, is similar to the one described for broadcast probing method with the exception that each probe should only contain \( p_o \) associated with its destination unlike broadcast probe which should contain \( p_o \) for all neighbors. The other method requires that link-layer re-transmission information about unicast probes should be supplied to the routing layer [6]. An average of link-layer re-transmissions would be the link’s ETX value.

Two factors distinguish the sensitivity of broadcast probes from unicast probes, i.e.,

1. unicast probes can use link-layer re-transmissions while broadcast probes cannot,
2. in general broadcast traffic is transmitted at a much lower rate in 802.11 networks.

Moreover, RTS/CTS could be used for unicast probes but the probes are comparable in size to RTS/CTS packets and there is no point in performing the handshake for probe packets. Looking at the two factors described above, artificial enhancement of the delivery probability of unicast probes by link-layer re-transmissions does not seem to be a logical strategy to faithfully capture the link strength. The second factor has conflicting consequences. On one side using lower rate modulation and coding ensure better reception in fading scenarios. However, on the other side, it means that packet spend more time in the channel than a higher rate one, suffering higher chances of collisions. If indeed a lower rate can make broadcast probes more sensitive to interference, using broadcast at data rate should resolve the problem and ETX could be estimated without incurring larger overhead of unicast probing.

4. EXPERIMENT SETUP

We have used NICTA’s wireless mesh testbed for our experiments (http://mytestbed.net/). The NICTA wireless mesh testbed is composed of 40 static nodes installed across
3 floors of at the NICTA office building in Sydney. A layout of a section of the testbed is shown in Fig. 1. In Fig. 1, the yellow (or light grey in greyscale) squares denote the location of mesh nodes and the numbers show their respective ID. The black squares and straight lines are irrelevant for our purpose. They show the power outlets in the building with which the mesh boxes are attached to. Each node consists of a Ubiquity SR2 Wireless Card with MADWIFI drivers supporting the IEEE 802.11a/b/g standards. We have installed the AODV-UU implementation (http://aodvuu.sourceforge.net/) of the AODV routing protocol on our testbed nodes. In all our experiments, we have configured the nodes to use 802.11a channel 56. 802.11a spectrum is relatively free of external interference and we are able to observe the effects of interfering flow without the environmental interference.

The AODV-UU implementation does not have ETX-enhanced routing protocol to run on wireless nodes. We augmented the code so that ETX can be calculated based on the reception of HELLO broadcast messages. In order to calculate ETX via unicast probes, we first wait for the node to know its neighbor via HELLO messages and then send one unicast message to each neighbor in each second. Since ETX calculation requires the delivery rate \( p_o \) over the outgoing links, the HELLO messages as well the special unicast probes carry the \( p_o \) values for the neighbors.

In our experiments, both broadcast and unicast methods are executed at the same time. We added a random jitter to avoid probe collisions. ETX is calculated over an interval of 10 seconds. In the experiments reported in this paper, we ran the augmented AODV on the nodes shown in Fig. 1, i.e., node 28 to node 33. AODV is launched on all nodes in the experiments at almost the same time. After couple of minutes a UDP flow of 54 Mbits/s is transmitted from node 29 to 31 for 3 minutes using Iperf tool. After the UDP flow, we left AODV running on the nodes for couple of minutes. Retransmission are turned off to observe fair comparison of both methods.

5. PRELIMINARY RESULTS

ETX values calculated via broadcast and unicast methods at node 28 associated with the links to all of the neighbors are shown in Fig. 2. The labels on y-axis show the neighbor id and the x-axis shows the time when the ETX values are calculated by the node. The flow started around 25500 s. It is very clearly visible that during the flow transmission, both values of ETX are badly affected and once the flow is over, the values become relatively stable again in general.

We classified all the links as: type-1, links used in interfering data flow, type-2, links with at least one node contributing in the interfering flow as a transmitter or receiver, type-3, links within the radio range of the data flow but do not contain any node related with the data flow. The difference in ETX values with and without data flow is shown in Fig. 3. Here type-1 are shown with blue color, type-2 with green color and finally type-3 with red color. The unicast based ETX values are slightly better than broadcast based ETX. The bars with ‘Inf’ show that ETX with data flow becomes infinity, i.e., none of the probes are received within 10 seconds of ETX estimation. Error bars show a single error deviation in upper and lower directions.

Due to the interfering data flow, the probes can be lost due to collisions, or could be delayed due to higher buffer occupancy. Although, the probes are given the priority over
data but carrier-sensing and back-off delays are greater in the scenario with interfering flow adding delays in the arrival of probes. If probes miss the ETX interval, the ETX calculation assumes it to be lost. In order to determine if the cause of much higher ETX value with interfering flow is collisions or delay, we draw Fig. 4 and Fig. 5. The difference in loss rate, i.e., number of lost probes/number of total probes, with and without interfering flow is shown in Fig. 4. It seems to be the dominating cause of higher ETX value when data is transmitted within the interfering range.

However, if collisions cause higher ETX value, turning on RTS/CTS should at least improve the situation but Fig. 6 does not show any significant improvement in the ETX sensitivity. Some of the links which were performing better are doing worse with RTS/CTS turned on. Note that the RTS/CTS option is turned on for packet sizes of over 1KB. We have experimented with both options one after another even though external interference might be playing a role here. Moreover, we configured the wireless interface via wlanconfig command and it might not be properly executed. We did not check by independent means if RTS/CTS is actually on or not.

6. CONCLUSIONS AND FUTURE PLAN
Packet collisions seems to be the dominating factor in increasing the ETX value of the link within the interfering range of a data transmissions. In our experiments, we did not see significant difference in unicast based ETX estimation and broadcast based ETX estimation. Both suffer a lot because of the interfering flow. Average probe delay might not be significantly affecting the ETX values. The results reported here are so far inconclusive and also not averaged over wide ranges of environmental conditions.

We are planning to perform several runs of the experiments. Also, we now have more advanced nodes in NICTA testbed with 802.11n interfaces and better drivers. We expect that the sensitivity of ETX estimation methods also improves with the new nodes. We are also planning to independently check the configuration options set for wireless interfaces of the nodes to ascertain that set options are actually implemented by the node or not.

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7. REFERENCES