# EX-ETT: MULTI OBJECTIVES EXPECTED TRANSMISSION TIME FOR AN IMPROVED LINK QUALITY ESTIMATION

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Abstract—Accurate and efficient wireless link quality evaluation in wireless networks is crucial in ensuring a good end-to-end network performance. However, due to the dynamic nature of the wireless mobile networks, estimating the link quality proves to be a challenge. This paper includes, a new link quality evaluation procedure that jointly considers the MAC (media access control) throughput and PHY (physical layer) characteristics for a more accurate link quality estimation. Our algorithm, termed as Extended Expected Transmission Time (Ex-ETT), is implemented depended on IEEE 802.11 and shows a momentous enhancement, higher than 80%, in terms of link quality estimation accuracy. The effectiveness of the proposed algorithm is demonstrated by an improved end-to-end routing decisions in the network. The numerical results display that, comparing with traditional method, the proposed Ex-ETT method lead to a better routing decisions in wireless mobile scenarios.

Keywords- Link quality estimation, rate optimization, informa- tion collection

## I. INTRODUCTION

Accurate and efficient Link Quality Estimation (LQE) method is necessary for making efficient operations as well as for improving the performance of multiple rates and multiple hops based on wireless networks standard IEEE 802.11. The metric, Packet Delivery Ratio (PDR) is always used for the measurement of wireless link quality. And it is the pre- requisite element to optimize the data rate and route selection [1]. However, many factors have effects on PDR, for example multipath, interference, shadowing and packet collisions. Con- ventional link quality estimation methods, which are normally based on received packet number or acknowledgment pack- ets, however, cannot provide a satisfactory and accurate link quality estimation untill now based on the knowledge today. Thus, gathering information sources from different layers and making a combination of them is necessary to provide enough information and consequently improves the network performance.

One of the commonly used link quality estimation methods is the ETT (Expected Transmission Time), which depends on ETX (Expected Transmission Count). However, this method only focuses on the length of data frame, link bandwidth and packet loss rate. A major drawback with the ETT method is its inefficiency to estimate the link quality with high accuracy. Thus, in this article, we come up with a new and improved link quality estimation approach, termed as Extended Expected Transmission Time (Ex-ETT). In Ex-ETT, in addition to the three parameters used in ETT, we also include other parame- ters to estimate the wireless link quality. The novelty of our proposed work lies in introducing additional parameters such as successful transmission time overhead, failed transmission time overhead, acknowledgment (ACK) time overhead and frame aggregation time overhead, for a more accurate link quality estimation.

The remaining of the article is organized as the following. Section II introduces the existing link quality estimation tech- niques available in wireless networks. Section III describes in detail our proposed Ex-ETT method in comparison with other existing methods presented in Section II. The performance evaluation and outcomes are presented in Section IV. Finally, the paper is wrapped up in Section V.

## II. EXISTING LINK QUALITY ESTIMATION METHODS

A number of LQE methods have been proposed over the years with Expected Transmission Count being the most common and extensively used method with the purpose of improving end-to-end throughput in multi-hop wireless net- works. Another metric being used as link quality indicator is the Expected Transmission Time. Both methods rely on hello packet delivery ratio [2] for finding high-throughput routes. This section discusses both ETX and ETT, in terms of opera- tion, overall performance, advantages as well as shortcomings.

1) ETX: ETX method was described by De Couto et al. [3]and the definition is that, on a wireless link, the total count of transmissions required to deliver a packet successfully. The aim is to find high throughput paths for transmission. ETX computing is based on IEEE 802.11 data link layer. It operates by sending 40 Bytes beacon packets at 2 Mbps rate to probe the link. We use the link's forward delivery ratios along with reverse delivery ratios to calculate ETX of a link [4].For the measure of probability that one of a data packet arrives the destination successfully along with the probability

such that the ACK packet is successfully received, reverse delivery ratio $P_{rd}$ following forward delivery ratio $P_{fd}$ are defined. Provided that the expectation probability that a transmission is received successfully and acknowledged is $P_{fd} \times P_{rd}$, then the definition of expected number is [4]:

$$ETX = 1/(P_{fd} \times P_{rd})$$

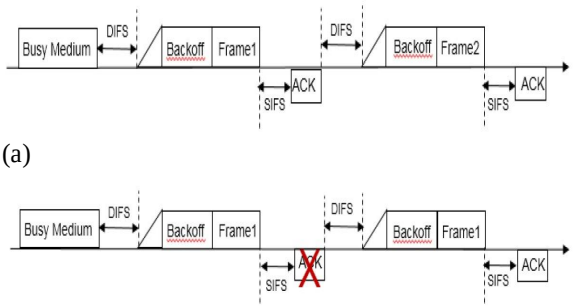
loss ratio on communication performance and it cannot reflect the changes in link bandwidth. To highlight, ETX considers neither the interference from the links, which significantly affects the link quality and transmission rate of packet, nor the load of the link, leading to unbalanced resource usage [7]. In addition, ETX infers that transmission rates are the same whatever the packet size, which could lead to mistaken estimation. ETT was introduced to mitigate the drawbacks of ETX, as discussed in the next subsection.

2) ETT: ETT method, an extension of ETX, was introduced by Draves et al. [5]. In comparison to ETX, ETT adds link bandwidth and packet size information in its calculations. The ETT evaluates time that is required by a packet to be transmitted successfully over a wireless link. For a single link, ETT can be elaborated as [6]:

$$ETT = L/B * ETX \quad (2)$$

where L shows size of packet or length and bandwidth of a link is represented by B. summing all the ETT values of each L links, ETT path metric is achieved. Main objective is to find a path having lowest sum of ETT values. Keeping additional parameters taken into considerations, ETT does not only provide a more accurate and reliable link quality estimation, but also could increase the overall network performance, as compared to its predecessor, ETX. ETT method can increase the path throughput by measuring the transmission capacity of the link. However, ETT still retains many disadvantages of ETX, such as, neglecting the link load, thus resulting in routing packets over existing heavily loaded nodes and links [7].

The main problem with the traditional probe-based LQE schemes such as ETX and ETT, is the inability to react quickly to link dynamics [2]. It may take some time for a node to learn and adapt to the link fluctuations. Second problem with these schemes is inaccuracy. Commonly, Probing of Hello packets is finished with immovable low data rates than the actual data rates. Such as, probing is done in 1-2 Mbps in the IEEE 802.11, but at the same time the actual data rate in IEEE standard 802.11g could be up to 54 Mbps and 200 Mbps in IEEE standard 802.11n networks. Besides, the size of the real data packet can be 1500 Bytes in comparison to probe Hello packet 40 Bytes. So, estimation relying on Hello packet calculation could become incorrect [8]. In order to alleviate these drawbacks, we introduce a new LQE method, that is the Ex-ETT presented in the next section.




(a)




(b)

Fig. 1: Sequence control and retransmission mechanism in Ex-ETT scheme. (a) Successful transmission (no retransmission). (b) Failed transmission (Frame1 retransmission).

## III. PROPOSED EX-ETT SCHEME

Our proposed Ex-ETT scheme operation is based on IEEE 802.11 medium access control architecture. The objective of Ex-ETT is to calculate the time to successfully transmit data frames over a link. The time taken to successfully transmit the frames, serves an indicator of the link quality in the network. The shorter the time taken, the better the link quality. For an improved link quality estimation, Ex-ETT not only depends on the frame size and link bandwidth information, but also uses four additional parameters in its calculation. The additional parameters are (1) successful transmission time overhead, (2) failed transmission time overhead, (3) ACK time overhead and (4) frame aggregation time overhead.

For a better understanding of our proposed Ex-ETT scheme, we divide our analysis based on three different scenarios. In the first scenario, we begin by analysing the case of transmitting a single data frame or a MAC Service Data Unit (MSDU). The transmission time of the frame relays on the corresponding transmission rate and the control rate in MAC layer. The frame transmission time is calculated in both rate modes, the transmission rate mode r and the control rate mode cr and is defined as:

$$T_{ft}(r) = t_{ov} + [L_{fs} + L_{rs}]/[L_{ss}(r)] \times t_{send}(r), \quad (3)$$

$$T_{ack}(cr) = t_{ov} + [L_{ack} + L_{rs}]/[L_{ss}(cr)] \times t_{send}(cr), \quad (4)$$

where $T_{ft}$ and $T_{ack}$ are the data frame transmission time (in transmission rate mode (r)) and the ACK transmission time (in control rate mode (cr)) respectively. $t_{ov}$ is the leading overhead time. $L_{fs}$ is the data frame size or the MSDU size in bytes, $L_{ack}$ is the ACK frame size in bytes, $L_{rs}$ is the transmission size

based on the transmission rate in bytes, $L_{ss}$ is the symbol size in bytes and $t_{send}$ is the sending time of each symbol.

In the second scenario, we analyze the case of transmitting multiple MAC Protocol Data Unit (MPDU) frames. The IEEE 802.11n protocol supports frame aggregation methods for in- creased throughput and reduced overhead. Frame aggregation is applyed to cut down medium contention overhead by mak- ing a combination of several Service Data Units into a single frame for transmission, i.e., combining several MPDUs into an Aggregate MAC Protocol Data Unit (A-MPDU). Assume there are N number of MPDU sub-frames in A-MPDU, the overhead time $t_{ov}$ and the transmission size $L_{rs}$ in Eq. (3) and (4) are evenly assigned to each MPDU. Therefore, the updated formula for transmitting multiple frames using frame aggregation method could be defined as:

$$T_{ft\ A}(r) = t_{ov\ A} + [L_{fs} + L_{rs\ A}]/[L_{ss}(r)] \times t_{send}(r), \quad (5)$$

$$T_{ack\ A}(cr) = t_{ov\ A} + [L_{ack} + L_{rs\ A}]/[L_{ss}(cr)] \times t_{send}(cr), \quad (6)$$

where $T_{ov\ A} = (1/N) \times t_{ov}$ and $L_{rs\ A} = (1/N) \times L_{rs} + 4$

Finally, in the third scenario, we consider the effects of successful and failed frame transmissions on the overhead time. Fig. 1 illustrates the retransmission mechanism imple- mented in Ex-ETT scheme during a failed transmission, with DIFS (DCF Inter-Frame Space) and SIFS (Short Inter frame Space) for contention coordination. In Ex-ETT, we adopt the backoff strategy based on the Binary Exponential Backoff method during retransmission to avoid network congestion. The backoff time could be calculated as:

$$T_{bf}(n) = 0.5 \min\{(2^{n+3} - 1), 1023\} * t_{slot}, \quad (7)$$

where n is the number of retransmission until the frame is successfully transmitted and $t_{slot}$ is a constant value depending on the channel bandwidth available. For example, for 5GHz bandwidth, the $t_{slot}$ = 9 µs. Based on Fig. 1, the successful transmission time $T_{succ}$ and the failed transmission time $T_{fail}$ could be calculated as in the following equations:

$$T_{succ} = \text{DIFS} + T_{ft} + T_{ack} + \text{SIFS} + T_{bf}(n), \quad (8)$$

$$T_{fail} = \text{DIFS} + T_{ft} + T_{ack} + T_{bf}(n) \quad (9)$$

Given $p_n$ and $p_k$ are defined as the probability of successful and the probability of failed transmissions respectively, the probability of successful transmission until n time is defined as:

$$P_n = p_n * \prod_{k=1}^{n-1} (1 - p_k), \quad (10)$$

Then, the time of successful transmission until n time is defined as:

$$T_n = T_{succ} + \sum_{k=1}^{n-1} T_{fail}, \quad (11)$$

Therefore, the expected transmission time of the data frame could be defined as:

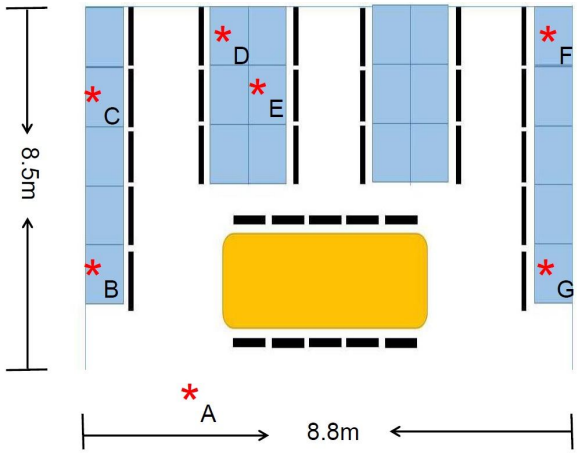



**Fig. 2: Test environment.**

## IV. EX-ETT LINK QUALITY ESTIMATION ANALYSIS

This section covers a comparison of the performance of Ex- ETT link quality estimation method, we proposed the existing ETT method through simulations using Wireshark and real experiment.

### A. Test Environment

We adopt the star topology of network in our test envi- ronment. Seven nodes A, B, C, D, E, F and G form this network being randomly distributed over the network and are connected in wireless communication link as illustrated in Fig. 2. The test is performed by randomly selecting three nodes, one node is selected as the source node, another node is set as the destination node and a third node, selected as a relay or trunk node to deliver the data starting source node and ends up on destination node. This experiment is repeated with ten different node combinations and node directions, as presented in Table I. By using different nodes located at different locations, changing the antenna directions and putting barriers (i.e., using wall partition in between nodes), we create different relay opportunities in different link conditions in our test environment. We measure the throughput of the direct communication link (source node to destination node) and the trunk communication link (source node to destination node via relay node) and then calculate the estimated frame transmission time in both direct and trunk links, using the existing ETT method and our proposed Ex-ETT method.

### B. Performance Comparison with Existing Method

As highlighted in the previous section, the objective of Ex- ETT is to calculate the time to successfully transmit data frames over a link. The frame transmission time indicates the link quality in the network. The link quality is deemed as high if the time taken for successful frame transmission to happen

$$\text{Ex-ETT} = 1/[1 - \Pi (1 - p_n)] \Sigma \{P_n * T_n\} \quad (12)$$

over the particular link is short. To illustrate this concept and to validate the performance of Ex-ETT in estimating the link quality, we calculate the frame transmission time in both direct link and trunk link using the current ETT approach

**TABLE I: Test Cases with Different Node Combinations and Antenna Directions.**

| | Node Combination | | | Distance (m) | | Antenna Angle (°) | | |
|---|---|---|---|---|---|---|---|---|
| | Source Node | Trunk Node | Destination Node | Direct Link | Trunk Link | Source Node | Trunk Node | Destination Node |
| 1 | A | B | C | 6.5 | 7.0 | 10 | 20 | 30 |
| 2 | A | C | D | 8.0 | 9.0 | 30 | 50 | 70 |
| 3 | A | E | F | 9.0 | 15.0 | 90 | 20 | 15 |
| 4 | B | D | F | 8.8 | 13.5 | 260 | 160 | 60 |
| 5 | B | F | G | 8.0 | 14.8 | 85 | 85 | 65 |
| 6 | C | E | F | 9.0 | 9.5 | 25 | 105 | 145 |
| 7 | C | F | G | 9.5 | 15.0 | 60 | 40 | 10 |
| 8 | D | E | F | 7.0 | 8.0 | 50 | 100 | 150 |
| 9 | D | F | G | 8.0 | 13.0 | 240 | 120 | 30 |
| 10 | E | F | G | 7.0 | 12.0 | 45 | 90 | 135 |

and the presented Ex-ETT scheme. Based on the calculated transmission time, we could observe the Ex-ETT's ability to correctly predict a better link to use for frame transmission. The outcome is presented in Fig. 3.

| Node Combination | Throughput (Mbps) | | ETT (μs) | | Ex-ETT (μs) | |
|---|---|---|---|---|---|---|
| | Direct Link | Trunk Link | Direct Link | Trunk Link | Direct Link | Trunk Link |
| 1 | 10.5 | 23.2 | 1359 | 578 | 1527 | 744 |
| 2 | 11.8 | 13.3 | 1284 | 1307 | 1550 | 1237 |
| 3 | 16.3 | 15.4 | 1071 | 1029 | 1326 | 1585 |
| 4 | 16.7 | 18.6 | 1037 | 826 | 1253 | 1257 |
| 5 | 19.8 | 14.8 | 824 | 1102 | 982 | 1344 |
| 6 | 20.6 | 17.2 | 792 | 948 | 1049 | 1256 |
| 7 | 23.4 | 29.5 | 647 | 582 | 924 | 733 |
| 8 | 27.5 | 39.1 | 593 | 417 | 786 | 553 |
| 9 | 27.7 | 44.9 | 589 | 363 | 780 | 481 |
| 10 | 28.5 | 25.0 | 612 | 607 | 758 | 865 |

**Fig. 3: Frame transmission time and link quality estimation 4.4 Comparison.**

Based on Figure. 3, link quality of the direct link and trunk link is denoted by the link throughput. In each node combination, the link which is having a better link quality (i.e., higher throughput) is shaded in grey. For both ETT and Ex-ETT, the correct link selections for routing the data frames, based on shorter frame transmission time, are shaded in blue. From the figure, we could observe that Ex-ETT could estimate the link quality with 90% accuracy as compared to ETT with only 70% accuracy. ETT selects a lower quality link for frame routing in node combination 2, 3 and 10 as highlighted in red. The judgment error is due to the small throughput difference between direct link and trunk link. Ex-ETT, on the other hand, has no problem identifying a better link for transmission and

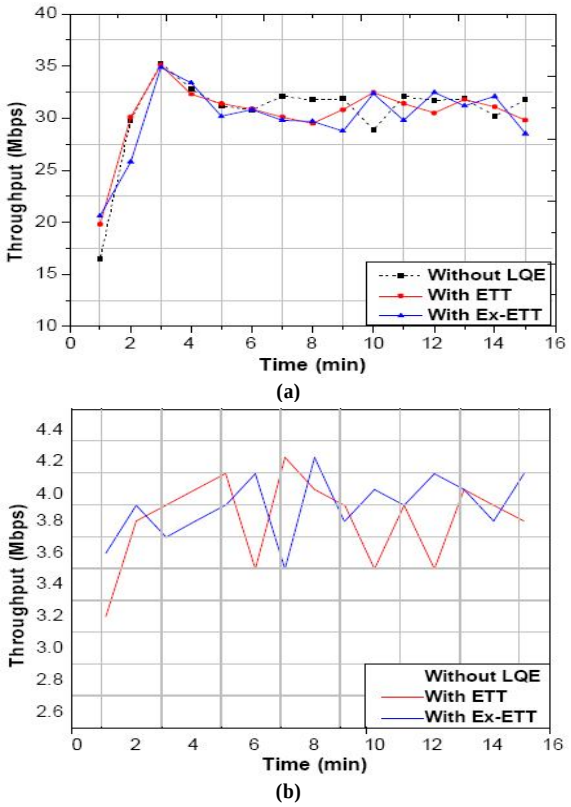



**Fig. 4: Average throughput comparison. (a) With 3 active nodes in the network. (b) With 7 active nodes in the network.**

routing even with links having almost similar characteristics. We also analyze the effects of implementing different LQE schemes on the mean end-to-end throughput in network. The outcomes are presented in Figure 4. In Fig. 4(a), we measure the throughput with and without LQE scheme implementation between the source node and destination node,having only three active nodes distributed over the network. If the link quality, not calculated or estimated, the average link through-

put is 31.6 Mbps. The average throughputs are 30.1 Mbps with ETT implementation and 29.8 Mbps with Ex-ETT implemen- tation respectively. There is a slight decrease in the throughput performance due to the LQE implementation. ETT scheme
contributes to 4.7% of throughput drops whereas Ex-ETT scheme affects the link throughput by 5.7%. In Fig.4(b), The number of active nodes in the network is increased to seven. The average throughput is recorded as 4.2 Mbps when the link quality is not estimated. Based on this figure, it is impressive to notice that both ETT and Ex-ETT implementations do not significantly affect the average throughput in the network. The average throughput is maintained as 4.1 Mbps when ETT or Ex-ETT is used to estimate the link quality. It is proven that the link evaluation and computation process in Ex-ETT, even with the new additional parameters introduced in the formula, do not degrade the overall network throughput performance.

## CONCLUSION

In this article, we have introduced a simple and practical link quality estimation method, termed as Extended Expected Transmission Time (Ex-ETT), which considers the physical characters on MAC layer as the main evaluation data sources. We combine the parameters typically used in the existing LQE schemes with four additional parameters; successful and failed transmission time overheads, ACK time overhead and frame aggregation overhead, for a more accurate link quality estimation. We have also shown that even with these newly added parameters, the proposed estimation method does not significantly affect the network throughput performance. In conclusion, Ex-ETT has the potential to improve the routing protocols performance and data transmission.

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