Effective Routing Scheme through Network Load-aware Route Metric in Multi-rate Wireless Mesh Networks

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Abstract: In multi-rate wireless mesh networks, a mesh node can dynamically modify the data rate on a particular link, in response to the perceived SNR ratio between neighbor nodes. In such networks, existing route selection schemes use a link quality metric based on the expected amount of medium time it takes to successfully transmit a packet. However, these schemes do not take into account the status of network load. Therefore, they may easily result in the network being overloaded. In addition, the application has no way of improving its performance under given network traffic conditions. In this paper, a new route metric that considers both per-hop service delay, estimated using the number of packets waiting for transmission in the output queue at relay nodes, and link quality is proposed. In addition, we propose the network load-aware AODV (NLA-AODV) protocol using the proposed metric. This protocol is implemented in a straightforward manner. The performance evaluation is performed by simulation using OPNET. It is demonstrated that the performance of the routing protocol using the proposed route metric outperforms routing protocols using other existing route metrics in multi-rate wireless mesh networks.

1 Introduction

As various wireless networks technology has evolved into next generation internet infrastructure, a key technology, wireless mesh networks, has emerged [AWW05]. Wireless mesh networks (WMNs), where potentially-mobile mesh clients connect over a static multi-hop wireless network consisting of mesh routers, are viewed as a promising broadband access infrastructure for both urban and rural environments. It is also believed that the development of techniques for high-throughput and low-latency multimedia traffic is important for many of the applications likely to be enabled by WMNs. In such WMNs, the relatively low spatial reuse of the single radio channel in multi-hop wireless environments, due to wireless interference, remains an impediment to the wide-spread adoption of WMN as an access technology. As the number of nodes in single-channel wireless networks increases, it has been shown that network capacity decreases [GK00].

The multi-rate transmission scheme has been used to overcome this problem. With the multi-rate transmission scheme, to obtain high-network capacity in multi-rate wireless mesh networks, it is necessary to find the result of the combined behavior of the medium access control protocol, routing protocol, and physical properties of a wireless network. In order to provide an understanding of how this combined behavior affects network throughput, several characteristics are examined. Mesh nodes can utilize the flexibility of multi-rate transmissions to make appropriate range, throughput, and latency trade-off choices across a wide range of channel conditions. While this flexibility has traditionally been used in link conditions, it has recently been proposed for use in route metrics [AHR04, DPZ04]. However, these metrics have problems in congested networks, and a new route metric that considers network-load status is necessary. This is described in section 3.

The main contribution of this paper can be summarized in the following section. Researchers have proposed many metrics to be used to discover a route between source and destination. However, these metrics do not consider queue delay in intermediate (relay) nodes over the end-to-end path. Hence, the problem of existing route metrics is presented and an analysis of end-to-end service delay that affect routing decisions in multi-rate wireless mesh networks, is presented. Based on this analysis, the general route cost for selecting an end-to-end route in such networks, is derived. The traditional technique used by existing ad hoc routing protocols select paths with minimum hop or with the expected lowest cumulative link transmission time in terms of the throughput. These paths tend to contain long range links that have low effective throughput and nodes with high queuing delay. However, in this paper the new route metric is proposed to select a path with low end-to-end. The new route metric tends to avoid the congested node and unreliable links. This results in an increase in overall network throughput.

The remainder of the paper is organized as follows. Section 2 describes previous work related to multi-rate wireless mesh networks. Section 3 describes the problems of using existing route metrics. Section 4 and 5 describe the new route metric and the proposed routing protocol. Section 6 summarizes the results of simulation studies. Section 7 presents the conclusion.

2 Previous Works Related to Multi-rate Technologies

Multi-rate transmission technologies in the multi-rate wireless mesh model presented in this paper are based on the 802.11 standard [IEEW]. The existing method for supporting multi-rate transmission is to leverage information which is already being collected by the MAC and Physical layers. An alternate technique used in [ABPWZ04], performs active probing at the network layer, in order to measure loss rates and estimate link speeds. This approach is unable to take advantage of the more advanced channel quality estimators, which are available at the lower layers. In addition, active probing techniques introduce additional network overhead proportional to the accuracy and rate at which they gather information. In this paper, inter-layer communication is strongly advocated; particularly between the MAC and Network layers. Several auto rate protocols have been proposed. The most commonly used protocol is Auto Rate Fallback (ARF) [PM99].

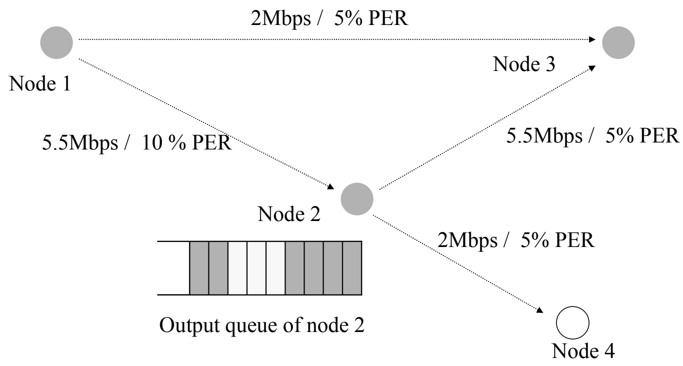


Figure 1: Example of estimating the number of backlogged packets per link in the sending node. Output queue at sending node has the 9 packets consisting of 6 packets waiting for transmission to node 1, and 3 packets waiting for transmission to neighbor node 2.

ARF operates using the link level ACK frames specified by the 802.11 standard. Each node increases the rate it uses to communicate with its neighbor after a number of consecutively received ACKs, and decreases the rate after a number of consecutively missed ACKs. As an alternative, the Receiver Based Auto Rate (RBAR) protocol was presented in [SKSK02]. RBAR allows the receiving node to select the rate. This is accomplished using the SNR of the RTS packet to select the most appropriate rate and communicating that rate to the sender using the CTS packet. This allows for much faster adaptation to the changing channel conditions than ARF. In addition, the Opportunistic Auto Rate (OAR) protocol, which is presented in [HVP01], operates using the same receiver based approach, and allows high-rate multi-packet bursts to take advantage of the coherence times of good channel conditions. These bursts also dramatically reduce the overhead by amortizing the cost of the contention period and RTS / CTS frames over several packets. In picking appropriate sized bursts, OAR also changes the fairness characteristics of each node, sending an equal number of packets to each node and obtaining the average time allocation. Therefore, in this paper, OAR is used as a multi-rate scheme.

3 Problems on Link Quality Metrics

The routing protocols have attracted a great deal of attention since the beginning of wireless ad hoc networks. Early exiting protocols were originally designed for single-rate networks, and used a shortest path algorithm with a hop-count metric to select routes. However, even if a route metric using minimum hop-count is an excellent criterion in single-rate networks, where all links from the node to its all neighbor nodes are equivalent, it does not accurately capture the trade-off present in multi-rate wireless mesh networks. The problem of route discovery using the hop-count metric in such networks has previously been discussed in [AHR04]. In [CAB03], the Expected Transmission Count Metric (ETX) is proposed to select paths that minimize the expected number of transmissions required to deliver a packet from source to destination. To deal with multi-rate links, [AHR04] defines the medium-time metric (MTM) for each transmission rate. MTM essentially measures the time it takes to transmit a packet over multi-rate links. It takes transmission delay into account (i.e. frame size divided by transmission rate) and the overhead, which in the case of IEEE802.11 includes RTS/CTS/ACK frames and channel contention. In [DPZ04], Weighted Cumulative Expected Transmission Time (WCETT) is proposed for using a routing metric for routing in multi-radio multi-hop static wireless networks. WCETT refers to the combination of the MTM with ETX as the Expected Transmission Time Metric. [DPZ04] addresses that fact that MTM+ETX provides a 16-55% increase in throughput over ETX alone and a 38.6% increase over route discovery using minimum hop-count routing in single radio networks. Their results in a multi-radio environment indicate that MTM+ETX achieve a median throughput increase of approximately 80% over ETX. An additional 10% throughput gain over MTM+ETX was achieved using the authors' proposed WCETT channel diversity strategy. However, the metric only takes link quality into account by having the metric inversely proportional to the transmission rate. The authors in [AHR04] used simulation to study the end-to-end UDP and TCP throughput of a multi-rate multi-hop path. This work reveals that if the interference range is infinity, then the unicast routing path that minimizes the total path delay also maximizes the throughput between the source and destination. However, in a real wireless network, the interference rage is finite. It is important to note that the inclusion of channel contention is required to account for the route metric.

To understand the problem of the route metric only taking into account link quality, the topology shown in Figure. 1 is considered with four nodes, labeled as nodes 1 to 4. For simplicity, node 1 is referred to as N1, and the network configuration is given in Figure. 1, there are 4 links to a node, each from neighbor nodes. It is assumed that all links are asymmetric. The transmission rate and quality of each link is presented in Figure. 1. The link quality based route metric determines link cost as the following two parameters: current bit rate in use, that is, the modulation mode and packet error rate at the current bit rate for a data frame with a 1000 byte payload.

It is assumed that N1 is the source node and wants to send a packet to N3. There are possible two paths: {N1, N3} and {N1, N2, N3}. Using MTM, the link cost of link (1, 3), link (1, 2) and link (2, 3) is 4ms, 1.6ms and 1.5ms, respectively. Thus, the route scheme only using the link quality metric selects the path {N1, N2, N3} of the lowest cumulative value. However, if N2 has 9 packets consisting of 6 packets waiting for transmission to node 1 and 3 packets waiting for transmission to neighbor node 2 in the output queue, the new packet that arrives at N2 must wait in a queue for a considerably long time, resulting in significantly increased end-to-end delay on the path {N1, N2, N3}. It is believed that if the link bandwidth of the estimated path is admitted by any flow, the path {N1, N3} can be more effective than the path {N1, N2, N3} in terms of end-to-end performance. This example illustrates the simple key idea.

In order to solve the problem above, a network load-aware AODV (NLA-AODV) protocol is proposed. This protocol is based on a new route metric that takes into account the quality of each link, queuing delay estimated with the number of packets waiting for transmission in the output queue at relay nodes, and contention delay during route set up.

4 New Route Selection Metric

The assumptions of networks using proposed routing protocol are presented below.

•All nodes in the networks are stationary.

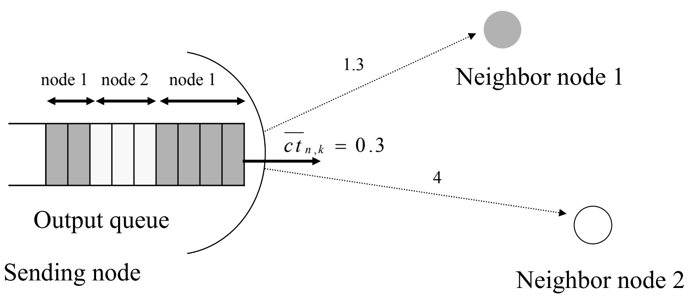
•All nodes have the function of multi-rate operation. In the networks each link operates at a different transmission rate.

Existing route metrics used to establish the end-to-end route are not efficient in multi-rate wireless mesh networks because they are only a measurement of transmission time, based on link quality and the reliability of a link, as shown in the previous section. The proposed approach is different, it estimates the number of packets waiting for transmission per link at each node and then predicts per-hop service delay based on the estimated number of packets, mean contention delay and link transmission time. In particular, with the predicted per-hop service delay of each node, more pertinent information of future end-to-end service delay is created, than existing strategies.

This section defines a new route metric for route discovery of single-hop or multi-hop paths targeted for multi-rate wireless mesh networks. In the proposed routing protocol, using the Hello message in AODV, the link state information generated by each node is transmitted to all neighbor nodes, this is used to estimate the quality of the link pair between neighbor nodes. A node must first calculate the link quality between neighbor nodes (mesh nodes) in mesh networks. The cost function for establishing a route combines two route costs consisting of the network load-aware and radio-aware route cost. The metric of each link also reflects the amount of channel resources consumed by transmitting the frame over a particular link. In the following subsections more details are given, illustrating the estimation of the proposed route metric.

4.1 New Route Metric

In this paper the Expected End-to-end Service Delay Metric (E^2SDM), which is a new route metric proposed to allow any shortest path based routing protocol to select a route with lowest end-to-end latency. The E^2SDM is defined as "network load-aware and radio-aware service delay" which is the end-to-end latency spent in transmitting a packet from source to destination. In order to estimate the E^2SDM value, the Expected Link Transmission Time (ELT^2) is used initially, for successfully transmitting a packet on each link and then multiplying ELT^2 by the mean number of backlogged packet in output queue at each relay node (relay mesh node). ELT^2 is similar to the MTM [AHR04]. The MTM assigns a weight to each link, equal to the expected amount of medium time it would take, by successfully sending a packet of fixed size S on each link in the network. The value depends on the link bandwidth and its reliability which is related to the link



Destinations	The number of backlogged packet	Link quality (ms)	The mean contention delay (ms)	Per-hop service delay (ms) in the sending node
Node 1	6	1.3	0.3	22.5
Node 2	3	4		

Figure 2: Example of calculating per-hop service delay in the sending node. Output queue at the sending node has the 9 packets, consisting of 6 packets waiting for transmission to node 1 and 3 packets waiting for transmission to neighbor node 2.

loss rate. The difference between the MTM and ELT^2 is the scheme estimating each parameter and the inclusion of contention delay in link metric. It is assumed that each node is serviced with a first-in-first-out (FIFO) interface queue. Let d_n be the expected time spent in transmitting all packets waiting for transmission through a link at node *n,* called per-hop service delay. d_n should take into account the expected service delay of any node such as queue delay, contention delay and transmission time of link *i* between node *n* and any neighbor node in the transmission range. With a given d_n, the E^2SDM of path, *p*, with h-hops, between source and destination, is estimated as follows:

$$\text{E}^2\text{SDM}\ (p) = \sum_{n=1}^{h} d_n \tag{1}$$

In order to estimate $d_{n,}$ *x* neighbor nodes in transmission range of node *n*, the mean number of backlogged packets is assumed, Let $N_{n,i}$ be the mean number of packets waiting for transmission on link *i* at node *n* to successfully transmit through link *i*. d_n is estimated as follows:

$$d_n = \sum_{i=1}^{x}\left(N_{n,i}\times\left(\overline{ct}_{n,k}+\text{ELT}^2\left(n,i\right)\right)\right)+\text{ELT}^2\left(n,i\right) \tag{2}$$

where the ELT^2 *(n, i)* is the ELT^2 of link *i* at node *n* and $\overline{ct}_{n,k}$ is the mean contention delay at node *n*.

As a result, route selection using the E^2SDM finds the path with the lowest end-to-end service delay in terms of current network load. In addition, a routing protocol using this metric can simultaneously perform traffic load balancing.

ELT^2 (n, i) is first defined as the link transmission time spent by sending a packet over link *i* at node *n*. This measure is approximated and designed for ease in implementation and interoperability. The ELT^2 for each link is calculated as:

$$\mathrm{ELT}^2(n) = \left[O_{control} + \frac{S_p}{r} \right] \times \frac{1}{1 - D_i} \qquad (3)$$

where $\overline{ct}_{n,k}$ is the mean contention delay, and the input parameters *r* and D_i are the bit rate in Mbs^{-1} and the frame error rate of link *i* for frame size S_p respectively. The rate *r* is dependent on local implementation of rate adaptation and represents the rate at which the node would transmit a frame of standard size (S_p) based on current conditions. D_i estimation is a local implementation and is intended to estimate the D_i for transmissions of standard size frames (S_p) at the current transmit bit rate used to transmit frames of size (*r*). In [IESP], the overhead of control is defined as listed in table 1. Figure. 2 presents the example of calculating the per-hop service delay.

Table 1 : The overhead of control

Parameter	Value (802.11a)	Value (802.11b)	Description
$O_{countrol}$	110μs	364μs	Protocol overhead
S_p	8224	8224	Number of bits in test frame

4.2 Estimating Nn,i and ELT2 in Per-hop Service Delay

The $N_{n,i}$ and ELT^2 value per link must be observed. The ELT^2 is estimated with the three types of link status. The three types of link status are mean contention time spent in the head-of-line packet to be transmitted to the physical layer, transmission rate per link, and reliability of each link. The methods of estimating the number of backlogged packets and the three types of status information are presented

– Mean number of backlogged packets estimation

The mean number of backlogged packets, $N_{n,i}$, is estimated by the data packet to use link *i* in the output queue at node *n*. Thus, $N_{n,i}$ is estimated per link. The link information used by an incoming packet can be known through the value of the next hop in the packet heard before sending the link layer. $N_{n,i}$ is estimated through measuring the number of both queued packets and dequeued packets. The number of dequeued packets includes the number of packet drops exceeding the limit of retransmission counter. The time-sliding window (TSW) estimator [CF98] is used to smooth the measured value. The TSW estimator is extremely simple. The TSW estimator works as follows:

Upon each packet arrival,

$$N_{n,i} = \frac{\alpha N_{n,i} + 1}{T_{\text{now}} - T + \alpha} \tag{4}$$

Upon each packet departure,

$$N_{n,i} = \frac{\alpha N_{n,i} - 1}{T_{\text{now}} - T + \alpha} \tag{5}$$

where α is window length measured in units of time and T_{now} and T are the time for a packet to arrive or depart, and the time when the previous packet arrived or departed, respectively. N_i is updated each time a packet arrives or departs.

– Mean contention delay estimation

This value is defined as the contention delay consumed for the head-of-line packet to be transmitted to the physical layer and is used to estimate the overhead of the transmission in the contending area. The contention delay includes the period for successful RTS / CTS exchange, if this exchange is used for that packet. Similarly, if the initial transmission of the packet is delayed due to one or more collisions generated by other nodes within the transmission range, multiple numbers of backoff periods may also be included. $\overline{ct}_{n,k}$ is estimated as the running average of the normalized contention delay of all packets belonging to the k th packet transmitted at node n. The weighted moving average is used to smooth the estimated value. Therefore, the mean contention delay is updated as follows:

$$\overline{ct}_{n,k} = \beta \overline{ct}_{n,k-1} + (1-\beta) n_{n,k} \tag{6}$$

where β is the weighting factor ($\beta < 1$) and $n_{n,k}$ is the contention delay achieved by k th packet. The initial vale $ct_{n,0}$ is set to a value adding the slot-time of DIFS[i] to the slot-time of the middle value between $CW_{min}(i)$ and $CW_{max}(i)$.

– The reliability of a link estimation

The estimation of the reliability of a link is based on the packet loss of a link. Here, type of packet drop is divided into two types, control message drop and data drop. Only the account data drop is used to estimate the reliability of a link. This drop means the number of packets estimated by the sending node as when the MAC cannot receive any ACKs for the (re) transmissions of those packets. For convenience, the mean drop rate of link i, D_i is estimated as follows;

$$D_i = \frac{Dr_i}{L_i} \tag{7}$$

where Dr_i is the loss rate of link i and L_i is the number of transmissions of link i between each neighbor node. Using TWS estimation, each parameter in equation 7 is estimated as follows;

$$Dr_i = \frac{\alpha Dr_i + 1}{T_{\text{now}} - T + \alpha} \tag{8}$$

$$L_i = \frac{\alpha L_i + 1}{T_{\text{now}} - T + \alpha} \tag{9}$$

where α is the window length measured in units of time and T_{now} and T are the time when a current packet is dropped or transmitted, and time when the previous packet was dropped or transmitted, respectively. D_i is updated when each packet is transmitted through link *i,* and dropped in link *i*.

5. Routing Scheme using E2SDM

In this paper, multi-rate wireless mesh routing using the expected end-to-end service delay metric is proposed. This route scheme is called the network load-aware AODV (NLA-AODV) protocol. The NLA-AODV protocol implements a modified version of AODV [PR00]. ADVD has been modified extensively to improve performance, and to support the E^2SDM.

The NLA-AODV protocol is based on the basic AODV functionality, including route discovery and route maintenance. In addition, this protocol includes new mechanisms for E^2SDM maintenance. We assume that the link-quality is not symmetric. In considering link pairs between node *a* and node *b*, the transmission rate of the link pairs is the same, but the loss rate between the two links is different, indicating that the reliability of two link between node *a* and node *b* is different. First, in the NLA-AODV protocol route discovery uses E^2SDM. When a node receives a RREQ message, including both a source and a destination address, it appends both its address and the per-hop service delay

ID	**The transmission rate**	**The reliability**	**Timestamp**
Neighbor ID 1	*r* bit rate in Mbs^{-1}	Drop rate	Time
. . . .	. . . .		. . . .
Neighbor ID N	*r* bit rate in Mbs^{-1}	Drop rate	Time

Figure 3: Hello message structure. The bold item in the first row is the node's own ID information. The following rows are the neighbor node's information.

metric. When a node sends a Route Reply, the reply carries back the complete list of link metrics for the route.

NLA-AODV uses a proactive mechanism to maintain the table of link metrics for the link transmission rate and the reliability of all neighbor nodes. In order to obtain information regarding the transmission rate between a node and its neighbor nodes, and update the table of link metrics, the Hello message in the AODV protocol is used. In using the Hello message, the information of the transmission rate of link *i* is appended onto the standard Hello message. In this paper, the algorithm for multi-rate decisions between nodes is available at [SKSK02]. The Hello message structure is shown in Figure. 3. Once a Hello message is received, a node updates the link information of neighbor node transmitting Hello message in the table of link metrics.

6 Performance Evaluation

In this section, OPNET v11.5 [OPM] is used to evaluate the performance of the NLA-AODV protocol using the E^2SDM, as compared to the routing protocol using medium-time metric (MTM) and hop-count (HOP) based route metrics. The routing protocol using MTM and HOP represents a routing scheme based on min link transmission time and min hop route selection, respectively. A fully connected topology is used to study the effects of node density, networks load, channel conditions, and node location. Then more general topologies consisting of a simple topology and more complex random topologies are considered. Finally, the impact between path length and the throughput of TCP is considered for multi-hop flows.

Simulation using the OPNET v11.5 is performed to evaluate the performance of E^2SDM, MTM and Min HOP route selection metrics. In simulation, RTS/CTS are enabled. With automatic rate control, the available rate between neighbor nodes based on IEEE802.11a is set from 6 Mbps to 54 Mbps. The mesh nodes are arranged such that several multi-hop routes to the destination are available.

6.1 Fully Connected Topology

In this scenario, the performance of the E^2SDM is studied using fully connected topologies in which all nodes are within radio range of each other. In these experiments the number of TCP transfers varies from 5 to 25, as each flow is between a source-destination pair of nodes, the number of each flow varies. There are 40 mesh nodes. Each flow randomly chooses the node as sources and destinations in the networks. The simulation continues for 200s. The metric used in measuring the metric' performance is the average end-to-end throughput. The simulation results are presented in table. 2. It has been proven from these results that the performance of the proposed NLA-AODV protocol outperforms that of existing routing protocols using other metrics (MTM and HOP) in end-to-end throughput. As expected, in overall situations, an improvement in end-to-end throughput (up to 200%) using MTM based routing protocol compared with the HOP based routing protocol is revealed. In addition, in simulation with low load (5 flows), throughput of both MTM and HOP is identical. This is because both metrics almost select the same path and the amount of traffic load in the current network topology does not result in saturation. The improvement in end-to-end throughput of the NLA-AODV protocol using E^2SDM compared with other metrics based routing protocol is shown. In particular, as the number of each flow increases, the full potential of the E^2SDM is revealed. The E^2SDM based path yields more than three times (up to 300%) the throughput of the HOP based path with higher traffic conditions and twice (up to 200%) the throughput of the MTM based path. This is because as queue delay increases at relay nodes, the NLA-AODV protocol selects paths that consist of both low queue delay and high link quality. It is verified that using the E^2SDM almost provides optimal end-to-end service.

Table 2. The performance of each service in one-hop ad hoc networks

# of traffic flows	Average end-to-end throughput (Mbps)		
	Hop count	MTM	E^2SDM
5	12.35	12.88	13.56
10	8.46	9.56	12.36
15	2.78	4.57	8.45
20	1.46	3.38	5.58
25	0.54	2.85	4.78

6.2 Throughput in Peer-to-peer Wireless Mesh Networks

The impact of routing metrics on the performance of the TCP connection is discussed. It is assumed that similar types of traffic will be present on community networks. The performance comparison is started with a simple scenario. There are 30 mesh nodes in a fixed area A of 2000m x 2000 meters in which a total of 50 TCP transfers between each unique sender-destination pair is carried out. Each TCP transfer lasts until simulation time ends and sends as much data as possible. In Figure. 4 the average throughput of the 50 TCP transfers for each metric is shown. As expected, the E^2SDM based path is proven to yield more than twice (up to 200%) the throughput of the HOP based path and the same (100%) throughput as the MTM based path. Therefore, the E^2SDM consistently selected the highest throughput path available in the networks.

The distribution of the path length of all 50 TCP transfers is illustrated in Figure. 5. In the 2-hop transmission range, the location of each node exists so the HOP metric mostly selects 1-hop and 2-hop paths, regardless of reliability. Therefore, the HOP metric only performs well when the direct link is of high link quality, and performs poorly when the direct link is of low link quality. However, MTM usually selects paths with 3-hop and 4-hop through link quality. Longer paths yield increased throughput than shorter paths because the MTM path utilizes the extra medium time available in long paths. However, even though the MTM selects paths with high link quality, this easily results in the network being overloaded. This is because each flow selects a similar path without considering the congested networks. In addition, in this situation, the application has no way of improving performance under a given network traffic condition.

The E^2SDM usually selects paths with 2-hop, 3-hop and 4-hop. This means that load-balancing of traffic works well. When using E^2SDM, these paths tend to contain long range links that have low effective throughput and high reliability, compared with MTM. However, this selects routes consisting of generally clear nodes (low congested node) with low end-to-end latency and high throughput. This results in an increase in overall network throughput. These results demonstrate the importance of taking into account both link quality and queuing delay in relay nodes, when selecting high throughput routing paths in multi-rate wireless networks.

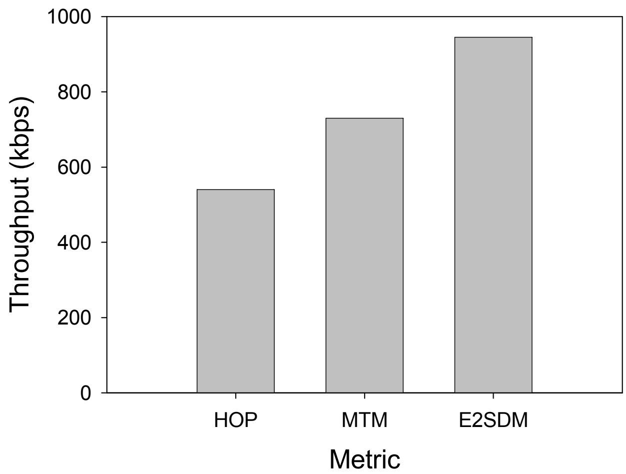


Figure. 4. Throughput of each metric

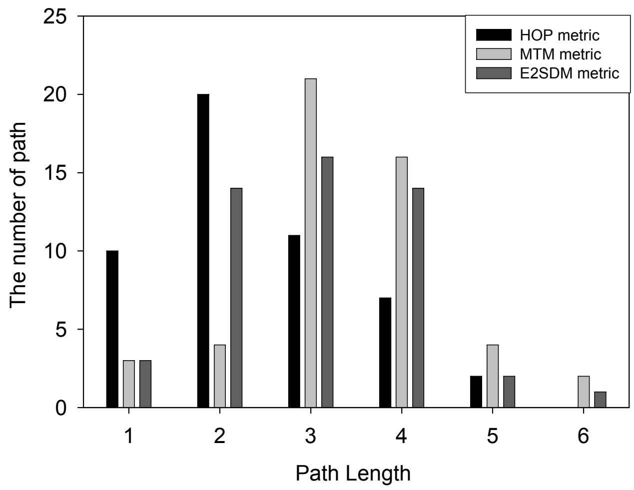


Figure. 5. The distribution of path length in 50 TCP transfers

7 Conclusion

In this work, it is demonstrated that existing route metrics only consider link quality as effective throughput in multi-rate multi-hop wireless mesh networks. In addition, existing route metrics tend to increase overall network congestion, because the mechanisms do not take into account the status of network load. Therefore, in such networks, the application has no way of improving performance under given network traffic conditions. In this paper, the Expected End-to-end Service Delay Metric, an improved technique for route selection in multi-rate wireless mesh networks, is presented. This metric is proportional to the time taken to transmit a packet on a given link, including both queuing delay and contention delay at relay nodes. This metric selects paths that have the highest effective throughput in terms of network load. In addition, a new routing protocol using the proposed metric, called the network load-aware AODV protocol, is presented. The simulation results reveal that the Expected End-to-end Service Delay Metric achieves significantly higher throughput and lower delay then alternative metrics. Up to 2.5 times more end-to-end TCP throughput than with the HOP or MTM metrics, is observed. The results demonstrate the importance of using per-hop service delay for selecting an end-to-end path with high throughput, and underscore the need for route scheme considering the current status of network load, in order to efficiently and accurately estimate end-to-end latency.

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