High-Throughput Path Selection Scheme for Multimedia Application in Wireless Networks

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Summary

To discovery a high-throughput path for multimedia application, such as 3D stereoscopic application, in wireless mesh networks, existing route selection schemes only use a link quality metric based on the expected amount of medium time it takes to successfully transmit a packet. Thus, these schemes may easily result in network congestion. This is because the current status of traffic load is not considered in routing metrics. In this paper, we describe the performance of existing routing metrics based on link quality and propose a new routing metric, called NLCRM (Network Load-aware and Contention-aware Routing Metric) that consider per-hop queuing delay, contention delay and link transmission time based on link quality for the current service level of network. In addition, NLCRM includes additional transmission delay at bottleneck link due to intra-flow interference in terms of the maximum throughput of intra-flow. Extensive simulations are carried out via the OPNET simulator. The simulation results demonstrate that NLCRM selects more accurate high-throughput routes, compared with existing routing metrics..

Key words:

Wireless Networks, Routing Metric, NLSR protocol

1. Introduction

As various wireless networks technology has evolved into next generation Internet infrastructure, a key technology, wireless mesh networks, has emerged [1]. Wireless mesh networks, where mesh clients connect over a static multi-hop wireless network consisting of mesh routers, are viewed as a promising broadband access infrastructure for commercial environments in which there are many of the applications that wants to be provided with high-performance from network. In other words, these applications need the high end-to-end throughput and low end-to-end latency.

Exiting works to improve performance in wireless mesh networks explores multi-channel MAC, adaptive transmission rate scheme and link quality based routing protocols [5, 6, 7, 8, 9]. However, they are not appropriate solutions for providing end-users with high-performance because these mechanisms are not designed in terms of the maximum end-to-end throughput that will be achieved by the end-user. In particular, the link quality based routing protocols are not accurate solution for providing high-throughput routes in congested networks because routing metrics do not consider the current status of traffic load in the network as well as transmission delay at bottleneck link due to intra-flow interference. Instead, more accurate performance metric that considers current service level of the network can be an alternative approach.

In this paper, we first present the performance of existing routing metrics based on link quality and then propose a network load-aware and contention-aware routing metric (NLCRM). In NLCRM, per-hop queuing delay, link quality and intra-flow interference are considered. NLCRM based route discovery can find routes that can achieve the higher end-to-end throughput as well as lower end-to-end service delay. Thus, application can be provided with more accurate high-throughput routes. The chosen route tends to avoid congested nodes and unreliable links. Moreover, routes with the low effect of intra-flow interference are selected. This results in an increase of overall network throughput. To demonstrate the effectiveness of NLCRM, we conduct extensive simulations via the OPNET simulator [10]. Simulations results indicate that NLCRM can support accurate high-throughput routes. In addition, it can be found that NLCRM can achieve higher aggregated throughput than other routing metrics.

The remainder of this paper is organized as follows. Section 2 describes the performance of existing works through analyzing the problems of using existing routing metrics. Section 3 and 4 describe a new routing metric and a routing protocol based on the proposed metric, respectively. Section 5 summarizes simulation results. Section 6 presents the conclusion.

2. Performance of Existing Routing metrics

Exiting protocols were originally designed for single-rate ad hoc environments, and used a shortest path algorithm based on a hop-count metric to select effective paths. However, they cannot accurately capture the trade-off presented in wireless mesh networks.

In [7], Expected Transmission Count Metric (ETX) is proposed to select paths that minimize the expected number of transmissions required to deliver a packet from

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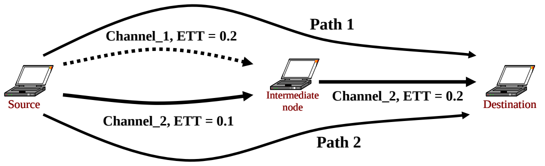


Route	SUM	MAX	WCETT (β = 0.5)	Achievable Max Throughput (packet/s) Due to intra-flow interference
Path 1	0.4	0.2	0.3	5
Path 2	0.3	0.2	0.25	3.3

Fig. 1. An example for calculating WCETT

source to destination over single-rate links. To deal with multi-rate link environments through ETX, in [6] medium-time metric (MTM) for each transmission rate is defined. MTM essentially measures the time it takes to transmit a packet over multi-rate links. It takes into account transmission delay (i.e. frame size divided by transmission rate) and overhead. MTM is similar to Expected Transmission Time (ETT) presented in [8]. In [8], Weighted Cumulative Expected Transmission Time (WCETT) is also proposed to consider the effect of the channel diversity in multi-radio multi-hop static wireless networks. The results in [8] addresses the fact that ETT provides a 16-55% increase in the throughput over ETX alone and a 38.6% increase over route discovery using the minimum hop-count metric. Moreover, the results in a multi-radio environment indicate that ETT achieves increased throughput of approximately 80% over ETX. An additional 10% throughput gain over ETT was achieved using the authors' proposed WCETT channel diversity strategy. However, these metrics only consider link quality, by having the metric inversely proportional to the transmission rate. Thus, more accurate high-throughput route cannot be provided in the high traffic load condition.

We also describe the performance of WCETT that takes the effect of channel diversity and intra-flow interference into account with the simple example shown in Fig. 1. In Fig. 1, using WCETT to discovery a high-throughput routes in multi-channel environments, the WCETT value of path 1 is more than one of path 2. Thus, path 2 as the high throughput route is chosen. However, in terms of the throughput of intra-flow, the throughput of path 1 is better than path 2. Since, in the case of path 2, all nodes belong with the mutual interference range. Thus, the throughput of path 29 is approximately 3 (packets/s) due to the data rate of the bottleneck link (channel_2 ETT =0.2) over path 2 (3.3 packets/s). This is due to intra-flow interference. However, in the case of path 1, both links can be used simultaneously to transmit a packet of intra-flow since there is not intra-flow interference. Thus, the throughput of path 2 is approximately 5 (packets/s) because the data rate of bottleneck link is 5 packets/s. WCETT may select an inaccurate high-throughput route. This is because transmission delay due to intra-flow interference over the established route is inaccurately considered in WCETT. Comparison of existing routing metrics is described in table 1.

Table 1. Comparison of existing routing metrics for wireless mesh networks

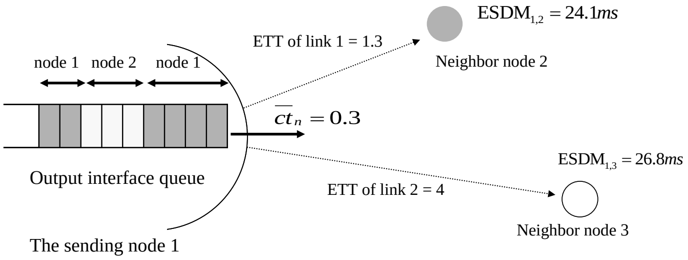
Routing metric	The considered routing cost for route discovery					
	Path length	Packet loss ratio	Link bandwidth (capacity)	Intra-flow interference	Queuing delay	Max Throughput
Hop-number [7]	YES	NO	NO	NO	NO	NO
ETX [9]	YES	YES	NO	NO	NO	NO
MTM [8], ETT [10]	YES	YES	YES	NO	NO	NO
WCETT [10]	YES	YES	YES	YES	NO	NO
NLCRM	YES	YES	YES	YES	YES	YES

3. A New Routing Metric to Establish a High-Throughput Route

In this paper, we assume that all mesh nodes are stationary. To consider the impact of channel diversity, we use the multi-radio at a node instead of obtaining the efficient impact of channel switching at single-radio. Since, in the case of multi-channel single-radio, the time for channel switching may be much larger than 224us [12]. Thus, the performance of a multi-channel MAC protocol will be significantly degraded [13]. Thus, we assume the network where each mesh node has multiple radios that are configured to different channels.

3.1 New Routing Metric

NLCRM is defined as a network traffic load-aware and link quality-aware routing metric that is the time spent in transmitting a packet between a source and a destination. NLCRM consists of ESDM(Expected Service Delay Metric) and the interference factor. Here, ESDM is defined as hop-by-hop service delay spent in transmitting a packet from a node to its neighbor nodes. Thus, ESDM includes per-hop queuing delay, contention delay and link transmission time. And we define the interference factor as additional transmission delay generated by intra-flow interference. NLCRM of a path, p, with h-hop number, h, is defined as



Destination	**The number of waiting packet**	**ETT (ms)**	**The mean contention delay (ms)**	**Per-Hop Queuing delay (ms)**	**ESDM (ms) , Per-Hop Queuing delay+ mean contention delay +ETT**
Node 1	**6**	**1.3**	**0.3**	**22.5**	**24.1**
Node 2	**3**	**4**			**26.8**

Fig. 2. An example of computing per-hop queuing delay and ESDM 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.

$$\text{NLCRM (p)} = \sum_{n=1}^{h} \mathrm{ESDM}_{(1-n)} + \text{Interference Factor.} \tag{1}$$

To determine the interference factor in NLCRM, we directly use the relation between the local bandwidth of bottleneck link (MinBandwidth) and the number of contention links (N) that interfere with bottleneck link in the route (the details can be found in [2]). The maximum throughput of intra-flow on the route is MinBandwidth/N [2]. In our work, ESDM can be inversely proportional to the available local bandwidth of a link. This is because it indicates service delay to transmit a packet between a node and its neighbor node. Thus, ESDM of bottleneck link (maximum ESDM on the route) can be inversely proportional to approximate MinBandwidth. N is determined by the number of links that use the same channel within interference range of bottleneck link on the route achieved by route discovery procedure. Transmission for packets of intra-flow is delayed for maximum ESDM at contention links. This is reason to add the interference factor to the sum of ESDM of each link on the route. In addition, the interference factor is to estimate additional transmission delay in terms of the achievable maximum throughput of intra-flow on the route. Thus, NLCRM provides more accurate the end-to-end service delay than WCETT in multi-rate multi-channel environments. Let SB be the set of links along a route. The interference factor is

$$\text{Interference factor} = \mathrm{N} \times \max_{i \in S_B} \mathrm{ESDM}_i \tag{2}$$

In our work, the value of N is determined by checking each node in the established route with the channel information of the node with maximum ESDM. Table 2 presents an example of computing the NLCRM values with the topology shown in Fig. 1.

Table 2. The example of computing NLCRM with Fig. 1. Assuming that queuing delay is the same at all nodes. Thus, the ETT value is proportional to the ESDM value

Route	Sum of all ESDM	Interference factor (N x max ESDM)	NLCRM	The chosen route
Path 1	0.4	0 x 0.2 = 0	0.4	√
Path 2	0.3	1 x 0.2 = 0.2	0.5	

3. 2 Expected Service Delay Metric

ESDM is determined with the per-hop queuing delay, the mean contention delay and ETT. Assuming that each node is serviced with a first-in-first-out (FIFO) interface queue, ESDMn, n+1 between node n and node n+1 is

$$\mathrm{ESDM}_{\mathrm{n}} = d_n + \overline{ct}_n + \mathrm{ETT}_{\mathrm{n,n+1}} \tag{3}$$

where d_n is per-hop queuing delay, $\overline{ct}_n$ is the mean contention delay at node n and $\mathrm{ETT}_{\mathrm{n,\ n+1}}$ is ETT between node n and node n+1. Fig. 2 presents an example of computing the ESDM values between a node and its neighbor nodes.

3.2.1 Per-hop Queuing Delay

Per-hop queuing delay is defined as the time delay when a new arrival packet stays within the queue before it is serviced by a wireless link. In order to estimate more accurate queuing delay in multi-rate environments, pre-hop queuing delay is determined by multiplying ETT per link plus the mean contention delay by the current number of packets waiting for transmission per link at each node.

Assuming that there are x-neighbor nodes in the transmission range of node n, d_n is

$$d_n = \sum_{i=1}^{x} \left(N_i \times \left(\overline{ct}_n + \mathrm{ETT_i} \right) \right) \tag{4}$$

where N_i is the current number of packets waiting for transmission to neighbor node i and $\mathrm{ETT_i}$ is the value of ETT between node n and node i.

In our work, N_i is estimated through measuring the number of both queued packets and dequeued packets per link. The link information used by an incoming packet can be known through the value of the next hop (address) in the packet header before sending to the link layer. The number of dequeued packets includes the number of packets successfully transmitted as well as the number of packets dropped due to exceeding the retransmission counter limit. Thus, this value is updated each time a packet arrives or departs.

3.2.2 Mean contention delay

The contention delay is defined as the time consumed for the head-of-line packet to be transmitted to the physical layer, and is used to estimate the transmission overhead 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 back-off periods may also be included. The weighted moving average is used to smooth the mean value. Thus, the mean contention delay is updated as

$$\overline{ct}_n = \beta \overline{ct}_{k-1} + (1-\beta) n_k, \tag{5}$$

where parameter β is the weighting factor and β < 1, whose optimum value has been computed to be 0.9, following a comprehensive simulation under traffic conditions, and n_k is the contention delay achieved by the k_{th} packet. Moreover, if a node uses multi-radio, this value is estimated per radio.

3.2.3 Expected transmission time

ETT [10] 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. ETT depends on the link bandwidth and its reliability, which is related to the link packet loss rate. ETT of link x between node n and node n+1 is

$$\mathrm{ETT_x} = \left[O_{control} + \frac{S_p}{r_x} \right] \times \frac{1}{1-R_x} \tag{6}$$

where the input parameters r_x and R_x are the transmission rate and the reliability of link x for frame size, S_p, respectively. R_x is estimated through the number of packet drop. Here, only the accounting data drop is used to estimate R_x. Thus, in this paper, only the packet drop on a wireless link, called a collision drop, is taken into account. In [3], the overhead of control $O_{control}$ is defined as listed in table 3.

Table 3. The overhead of control

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

4. ROUTING PROTOCOL USING NLCRM

In this section, we propose a routing protocol, called a network load-aware source routing (NLSR) protocol based on NLCRM. The NLSR protocol selects the path with minimum NLCRM for a high-throughput route.

The NLSR protocol is a modified version of AODV [11]. The NLSR protocol uses basic AODV functionality, including route discovery and route maintenance. In addition, it includes new mechanisms for ESDM 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. In the NLSR protocol, ESDM is first used for route discovery. When node n receives a route request (RREQ) message, including both a source and a destination ad-dress, it appends both its own address, cumulative ESDM from a source to the previous node of node n and the per-hop queuing delay of the node in a RREQ message that is sent to neighbor nodes, it also appends ETT for the link over which the RREQ message arrived. Fig. 3 shows the RREQ message structure. When the RREQ message arrives at the destination, it computes determines the interference factor of the received RREQ message and then determines NLCRM of a route. The NLSR protocol uses a route reply (RREP) message back to the source to establish a route. At this time, this RREP is delayed up to one second waiting for a piggy-backing opportunity.

The NLSR protocol uses a proactive mechanism to maintain the link quality metrics for the link transmission rate and the reliability of all neighbor nodes. In order to

…….	Cumulative ESDM from source to node_N	Min (ESDM), Interface ID, Node_X	ESDM, Interface ID, node_0 (source)	ESDM, Interface ID, node_1	ESDM, Interface ID, node_2	..	ESDM, Interface ID, node_N	..

Fig. 3. RREQ message structure.

obtain in-formation regarding the transmission rate between a node and its neighbor nodes, and update the link quality 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. When a hello message is received, a node updates the link information of neighbor node transmitting the Hello message in link quality metrics.

5. PERFORMANCE EVALUATION

To test the performance of NLCRM, with comprehensive simulations, the NLSR proto-col is evaluated and compared with other routing protocols based on the Minimum-HOP (MHOP), ETT and WCETT metrics. RTS and CTS are enabled. The topologies vary according the different simulation purposes. Simulations are conducted using the OPNET v11.5 simulator [10]. In the first scenario all mesh nodes have the 802.11b radio and use the OAR [5] for a multi-rate adaptation. In other scenarios 802.11a and 802.11g is used at each mesh node and the transmission rate between neighbors nodes are related to the distance between the nodes as shown in table 4. In the simulations, the UDP throughput, TCP throughput, and the distribution of path length, according to the amount of traffic-load in the network, are studied.

Table 4. The overhead of control

Distance (m)	25	50	75	100	125	150	175	200	225	250	More than 250
Rate (Mbps)	54	48	36	24	18	12	9	6	2	1	0

5.1 "ETT" Versus "NLCRM" based on route selection in the congested network

To simplify the explanation, we use the topology shown in Fig. 4. The topology is com-posed of 25 mesh nodes. Node 1 is the source and node 25 is the destination. For medium access, the distributed coordination function (DCF) in IEEE 802.11 [4] is assumed, as the access method used in ad hoc mode. The small dotted box indicates the background traffic zone in which the background traffic is generated from 0.1 Mbps to 0.5Mbps. The source-destination pairs for the background traffic are chosen randomly in the zone. The source sends packets to the destination using a 0.25Mbps sending rate. We use ETT, instead of WCETT since WCETT is aimed to be used only in multi-channel environments. We run simulations using NLCRM and ETT for 300s. n case of the generated background traffic from 0.1 to 0.2Mbps in the background traffic zone, using both metrics to establish a high-throughput route, the chosen route goes through nodes 2, 15, 14, 22, 10, 20, and 25 (the solid line 1 in Fig. 4). In the case of the background traffic from 0.3 to 0.5 Mb/s, ETT selects the route that goes through node nodes 2, 15, 9, 8, 7, 21, 20 and 25 (the solid line 2 in Fig. 4). NLCRM selects the route that goes through nodes 2, 16, 17, 23, 7, 21, 20 and 25 at the background traffic of 0.3 and 0.4 Mb/s (the

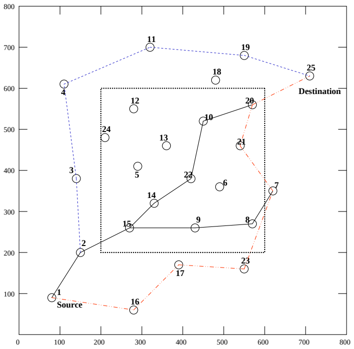


Fig. 4. Scenario used to perform the simulation in congested network.

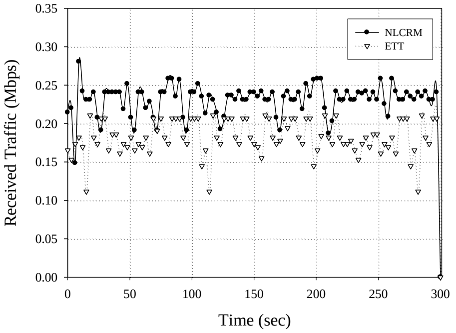


Fig. 5. The received traffic in the case of the background traffic of 0.5Mbps.

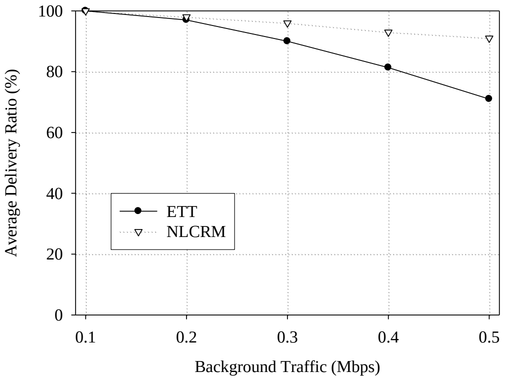


Fig. 6. Average Delivery Comparison

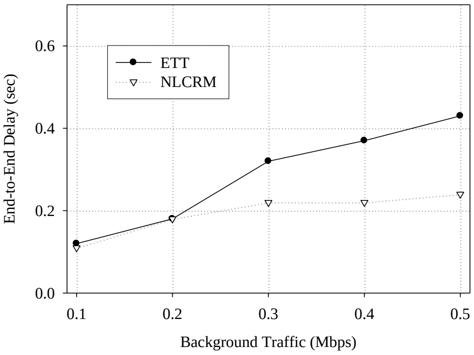


Fig. 7. Average Delay Comparison

dashed line in Fig. 4) and the route that goes through nodes 2, 3, 4, 11, 19, and 25 at the background traffic of 0.5 Mb/s (the dotted line in Fig. 4). These results indicate that NLCRM avoids the congestion zone.

Figs. 5, 6 and 7 show the received traffic, the average deliver ratio and end-to-end delay, respectively. At the low traffic-load, the packet delivery ratio of ETT and NLCRM is almost identical. This is because both metrics almost select the same path as shown in Fig. 4 and the level of traffic load over the zone does not result in network congestion. However, as the amount of traffic load increases, an improvement in packet delivery ratio and delay using NLCRM, compared with ETT, is revealed. Thus, in simulation results, it is verified that NLCRM can support more accurate high-throughput routes

5.2 Throughput in Multi-rate Single-radio Wireless Mesh Networks

In this scenario, multi-rate single-radio wireless environments are considered using random topology, where 40 mesh nodes are located in 2000m x 2000m square regions. There is the number of TCP flows that varies from 5 to 25. Each TCP flow lasts until simulation time ends and sends as much data as possible. The simulation runs for 300s. Fig. 8 shows the average throughput of all TCP flows. This result demonstrates that average TCP throughput achieved by the NLSR protocol shows better than the MHOP and ETT metrics based routing protocols. As expected, in low traffic load over the network (5 TCP flows), the average TCP throughput of all routing metrics is almost identical. This is because these metrics usually select the same route in the unsaturated networks. However, as the number of TCP flow increases, the improvement in the average TCP throughput achieved by the NLSR protocol, compared with other routing protocols, is shown. The average TCP throughput is increased up to 300% using NLCRM, compared with using MHOP and up to 150% using ETT. This is because as the amount of traffic load over the network increases, the per-hop queue delay is significantly increases. In addition, the NLSR protocol selects routes with the achievable maximum throughput in terms of intra-flow. Fig. 9 shows the distribution of the path length in the case of 25 TCP flows. MHOP mostly selects 1-hop, 2-hop and 3-hop paths, regardless of the current status of network. Thus, MHOP provides end-users with low-performance in high traffic load over the network. ETT, however, mostly selects 2-hop and 3-hop paths. Once in a while, it selects 5-hop and 6-hop paths. That is, longer paths yield increased throughput than shorter paths because ETT utilizes the extra medium time available in long path to find high-throughput routes. However, even though ETT selects routes with high link quality, this can easily result in the network being overloaded, because each flow selects similar routes that consist of congested nodes. However, NLCRM usually selects routes with hop number from 2 to 6. The simulation results demonstrate that using NLCRM, traffic load-balancing works well.

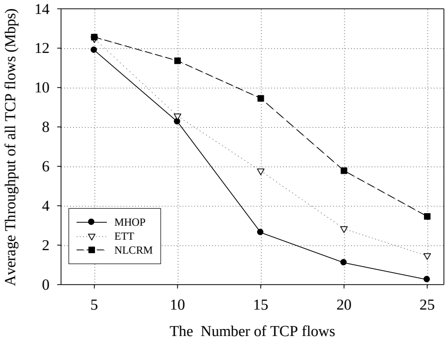


Fig. 8. The average throughput of all TCP flows

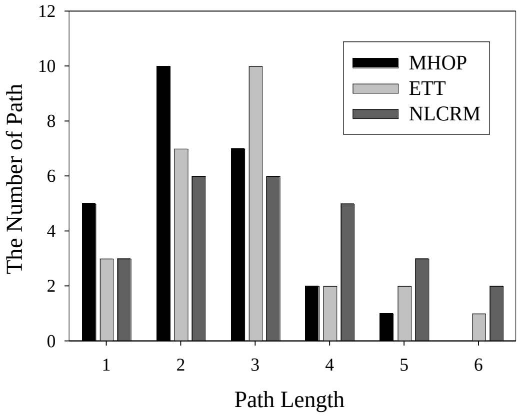


Fig. 9. The distribution of path length of 25 TCP flows

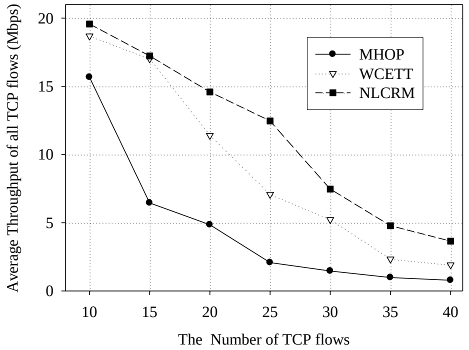


Fig. 10. The average throughput of all TCP flows

5.3 Throughput in Multi-rate Multi-radio Wireless Mesh Networks

To test the performance of NLCRM in multi-rate multi-interface mesh networks, we assume that all nodes have two radios that are configured to different channels in the simulation. The 802.11a radio operates on channel 36 and the 802.11g radio operates on channel 10. the β in WCETT are set to 0.5. The simulation environments are the same as the previous scenarios. Fig. 10 shows the simulation results of the average TCP throughput. There is an improvement in the average TCP throughput of NLCRM, compared with other metrics. The average TCP throughput using NLCRM is up to 250% greater than MHOP and up to 200% greater than WCETT in high traffic load over the network. Therefore, NLCRM consistently selects the highest throughput route available in the networks. The distribution of the path length of 40 TCP flows is shown in Fig. 11. WCETT usually selects 3-hop and 4-hop paths. However, NLCRM usually selects 2-hop, 3-hop and 4-hop paths. Simulation results also show that traffic load-balancing works well by NLCRM in multi-radio environments.

6. Conclusion

In this paper, we analyze that the performance of existing routing metrics for wireless mesh networks. Existing routing metrics tend to increase overall network congestion because these metrics do not accurately take into account the status of traffic-load in network as well as the expected end-to-end throughput for intra-flow. To solve the problems, NLCRM, an improved routing metric for routes with more high-performance for mesh networks, is presented. This metric is proportional to the time taken to transmit a packet on a given link, including queuing delay and contention delay, ETT at mesh nodes and the delay time generated by intra-flow interference. Moreover, it can select routes that achieve more accurate high-throughput than other metrics. In addition, the NLSR protocol using the proposed metric is also presented. Simulation results demonstrate that the NLSR protocol can significantly achieve higher throughput and lower delay than other routing protocols based on alternative metrics.

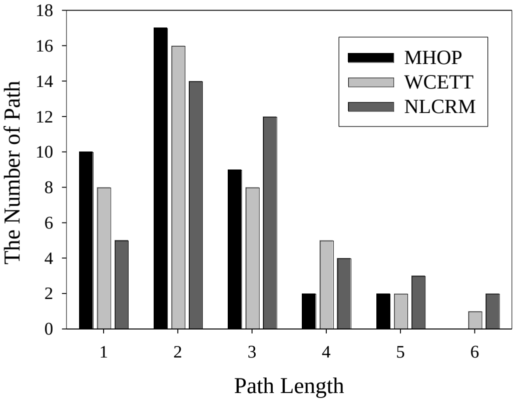


Fig. 11. The distribution of path length of 40 TCP flows

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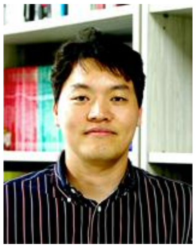

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