A Comprehensive Comparison of Routing Metrics for Wireless Mesh Networks

Hui Liu, Wei Huang, Xu Zhou, and X. H. Wang

Abstract—**It is well-known that finding paths with minimum hop count leads to poor performance in wireless mesh networks (WMN) because the assumption of the same transmission failure probability in all links may not be true. A routing metric can assist traditional routing protocol in selecting better paths by explicitly taking the interference, delay etc. into account. This paper presents a thorough review and a comparison of 10 kinds of routing metrics designed for diverse QoS requirements in WMN. Meanwhile, this paper classifies these routing metrics into three basic types, ETX-based metrics, mETX, and some other metrics less attractive to WMN routing layer, for better understanding and future applications. To the best of our knowledge, no paper except this one has such a comprehensive review of routing metrics utilized in WMN.**

I. Introduction

In the world of ubiquitous mobile wireless networks, wireless mesh networks (WMN) [1] recently emerge as a significant and promising technology due to its flexibility, rapid deployment and low cost. A WMN is constituted of mesh routers and mesh clients, the former forming a wireless mesh infrastructure and the latter accessing the wireless mesh infrastructure through mesh routers.

WMN is a promising technology in emergency management. Several pilot projects have shown the effectiveness of application of WMN in emergency situations [2]-[4]. Emergency management needs high capacity to deliver multi-media information. To achieve a high network capacity, a variety of WMN routing protocols were designed to find effective paths with low traffic overhead and packet delay[5]-[9]. However, most current routing protocols select paths with minimal hop count, which leads to poor performance because the links in the chosen paths may be lossy or slow. To meet higher demand on network throughput, IEEE 802.11 standard provides multiple channels available for use [10], [11]. As diverse multi-channel WMNs deploying non-overlapping channels are appearing, the routing metrics, hop count or Expected Transmission Count (ETX), cause even worse performance than before when cooperating with routing protocols for multi-channel WMN. Thus, to meet specific QoS requirements in various WMNs, appropriate QoS metrics are proposed to measure bandwidth, packet or channel-switching delays, packet loss rate, and interference [12], [13] etc, which largely improve network capacity.

On account of the importance of routing metrics in routing protocols, this paper summarizes 10 types of routing metrics and classifies them into 3 classes: ETX-based metrics, mETX, and some other metrics used in WMN. Also, the limitations and performance comparison of these routing metrics are presented in this paper for better understanding and future applications.

The rest of the paper is organized as follows. Section II describes three routing protocols utilized in WMN. The classification and comparison of routing metrics are arranged in section III. Finally, concluding remarks are formulated in the last section.

II. Routing Protocols for WMN

In order to make routing metrics well understood, in this section, we generally describe three different basic routing protocols linked to WMN with which routing metrics are incorporated to find the "best" paths.

A. The Destination Sequence Distance Vector (DSDV) routing protocol

DSDV [14] is a proactive unicast routing protocol which is based on the traditional Bellman-Ford (Distance Vector) algorithm. To avoid formation of route loops in the traditional Bellman-Ford, sequence numbers are used in DSDV to distinguish stale routes from fresh ones. In routing tables of DSDV, an entry stores the next hop towards a destination, the cost metric for the routing path to the destination and a destination sequence number that is created by the destination. Each node periodically transmits updates including its routing information to its immediate neighbors through time-driven or event-driven. In DSDV, only the route with the highest sequence number can be used in the packet transmission. If two routes have the same sequence number, the optimistic route with certain metric will be chosen. DSDV only supports bi-directional-link networks.

B. The Dynamic Source Routing (DSR) protocol

DSR [15] is a reactive routing protocol, allowing nodes to discover dynamically the multi-hop routes to the destinations with source routing algorithm. In source routing algorithm, each data packet contains complete routing information to reach its destination. There are two major phases in DSR, the route discovery, and the route maintenance. For the route discovery, the source node broadcasts a route request

Hui Liu and Wei Huang are with the School of Communication and Information Engineering, University of Electronic Science and Technology of China (e-mail: plywellcn@yahoo.com.cn, weihuang@uestc.edu.cn).

Xu Zhou is with National Lab of Radar Signal Processing, Xidian University, Xi'an, China (e-mail: ctizhou@sina.com).

X. H. Wang is with Institute of Advanced Telecommunications, Swansea University, Swansea SA2 8PP, UK (phone: +44 1792 602573; fax: +44-1792 602449; e-mail: xinheng.wang@swansea.ac.uk).

message with its source routing table. The node which receives the request message appends its own address to the route table in the routing message and forwards it to its neighbors until either the destination or the intermediate node that contains the route information to the destination receives the message, and then transmits route reply. DSR has route cache to maintain the route information. DSR has increased traffic overhead by containing complete routing information into each data packet, which degrades its routing performance.

C. The Ad Hoc On-demand Distance Vector Routing (AODV) protocol

AODV [16] is another reactive on-demand routing protocol for mobile ad hoc networks which is based on both DSR and DSDV, so absorbs the advantages of both protocols like destination sequence number to avoid route loops. Compared with DSDV and DSR, in AODV, a node only needs to maintain the routing information about the source and destination as well as the next-hop, so largely cuts back the traffic overhead. The process of route discovery is parallel to DSR. Route request (RREQ) packets are broadcasted for route discovery while route reply (RREP) packets are used when active routes toward the destination are found. Meanwhile, HELLO messages are broadcasted periodically from each node to its neighbors, informing them its existence.

III. Comparison of Routing Metrics for WMN

We have discussed several relative issues about WMN for better understanding of routing metrics. It is well-known that picking the path with the smallest number of hops between two nodes often leads to poor performance, because such paths tends to use links that could have marginal quality. This minimum hop-count metric does not explicitly take costs between links or nodes like delays, bandwidth, packet loss, and interfere into account. As a result, in this section, we will describe and analyze ten QoS (Quality of service) routing metrics which are classified into 3 types: ETX and the metrics based on it, modified ETX (mETX), and other metrics.

A. ETX and the Metrics based on it

1)ETX:ETX proposed in [17], measures the expected number of MAC transmissions and retransmissions needed to successfully deliver a packet from the sender to the receiver. The ETX of a link is the predicted number over a link; the ETX of a route is the sum of the ETX for each link over the route. The derivation of ETX starts by measuring the underlying packet loss probability in both the forward and reverse directions denoted by d_f and d_r. Let p denote the probability that the packet transmission from node x to y in a link is not successful: $p = 1-(1-p_f)*(1-p_r)$.

Also, assume the probability that the packet will be successful received by node y after k attempts denoted by s(k). Then, $s(k) = p^{k-1}*(1-p)$.

Finally, ETX is acquired mathematically using series theory:

$$ETX = \sum_{k=1}^{\infty} k * s(k) = 1/(1-p). \tag{1}$$

When ETX is measured in a link of a real network,

$$ETX = 1/(d_f \times d_r) \tag{2}$$

where d_f is the forward delivery ratio, the statistically measured probability of $1-p_f$, while d_r is the reverse delivery ratio, the statistically measured probability of $1-p_r$. Both d_f and d_r mean the probability of the successful packet delivery in the forward or reverse direction. The delivery ratio d_f and d_r are measured by broadcasting dedicated link probe packets of a fixed size every average period τ (a typical value is 1 second) from each node at its neighbors. Each node remembers the probes it receives during the last w second (usually 10 seconds). At any time t, a node can calculate the delivery ratio from a sender using

$$r(t) = count(t-w,t)/(w/\tau). \tag{3}$$

Count (t-w, t) is the number of probes received during the window w, and w/τ is the number of probes that should have been received. Calculation of a link's ETX requires both d_f and d_r. So, each node directly counts the probes sending by its neighbors and acquires the number of probes it forwards to any of it neighbors and containing in probes sending by its neighbors. So, this allows it to calculate d_f and d_r in any link involving this node. The ETX of a route is the sum of the links' ETX. The implementation of ETX is on DSR and DSDV.

As a routing metric for single-channel multi-hop wireless network, ETX is widely used in WMN or as a foremost factor considered in many routing metrics for WMN proposed after it, like WCETT (Weighted Cumulative Expected Transmission Time). The advantages are that it is based on delivery ratios, which directly affects throughput and accounts for the effects of link loss ratios and asymmetry in the loss ratio between the two directions of each link. Meanwhile, it tends to minimize spectrum use, which should maximize overall system capacity. However, it only captures link loss ratio, ignoring the interference experienced by the links which has a significant impact on the link capacity and the data rate at which the packets are transmitted over each link. Besides, since broadcast probe packets are small and sent at the lowest possible data rate, ETX may not reflect the same loss rate as data packets sent at higher rates. Meanwhile, it might vary when there is very high load due to 802.11 MAC unfairness or when there is delay of the broadcasted packets due to a busy link. Furthermore, when typical wireless channels experience variations at many time-scales other than relatively static, poor performance happens because ETX uses the mean loss ratio in making routing decisions without considering channel variability. Modified ETX (mETX) provides an effective solution to this challenging problem.

2)WEIGHTED CUMULATIVE EXPECTED TRANSMISSION TIME (WCETT):WCETT [18] is a routing metric proposed in Multi-Radio Link-Quality Source routing(MR-LQSR) protocol which combines WCETT and DSR, can be used for multi-radio, multi-hop WMN. Firstly, it proposes the Expected Transmission Time (ETT) which improves on ETX by making use of the data rate in each link. The ETT of a link is defined as follows:

$$ETT = ETX * S / B \tag{4}$$

where S denotes the size of the packet (for example, 1024 bytes) and B is the bandwidth of the link. ETT explains the expected MAC transmission time of a packet of a size S over certain link. Given the presence of multiple channels and intra-flow interfere, WCETT is defined as:

$$WCETT = (1-\beta) * \sum_{i=1}^{n} ETT_i + \beta * \max_{1 \le j \le k} X_j \tag{5}$$

where X_j is the sum of ETT of the links in path p operating on channel j, assuming the system has a total of k orthogonal channels available. β is a tunable parameter subject to $0 \le \beta \le 1$. There are two components in the WCETT metric: the first component contributes to find the path with the least summation of ETT; the second accounts for the bottleneck channel dominating the total path throughput.

WCETT is based on ETT and aware of the loss rate (due to ETX) and the bandwidth of the link (B). The primary advantage of this metric over ETT is that it explicitly accounts for the reduction in throughput due to interference among links that operate on the same channel. So, WCETT can support multi-radio or multi-channel wireless networks. In addition, the two weighted (tuned by β) components of it substitute the simple summation of ETT and attempt to strike a balance between throughput and delay, global good and selfishness.

A main disadvantage of WCETT is that it fails to hold the property of isotonicity [19] which is needed to find loop-free and minimum weighted paths. However, AODV or DSR based on Bellman-ford algorithm can use non-isotonic metrics to route efficiently, which can otherwise somewhat make up WCETT's drawback. Also, it does not capture inter-flow interference compared with Interference Aware Routing Metric (iAWARE).

3)METRIC OF INTERFERENCE AND CHANNEL SWITCHING (MIC):This metric [12], [20] proposes a scheme for multi-channel WMN to improve WCETT by solving the problem of inter-flow interference as well as non-isotonicity. MIC for a path p is defined as follows:

$$MIC(p) = \frac{1}{N \times \min(ETT)} \sum_{link\ l \in p} IRU_l + \sum_{node\ i \in p} CSC_i \tag{6}$$

where N is the total number of nodes in the network and min (ETT) is the smallest ETT in the network. The two components of MIC, IRU (Interference-aware Resource Usage) and CSC (Channel Switching Cost), are defined as:

$$IRU_l = ETT_l \times N_l \tag{7}$$

$$CSC_l = \begin{cases} w_1 & if \quad CH(prev(i)) \ne CH(i) \\ w_2 & if \quad CH(prev(i)) = CH(i) \end{cases} \quad 0 \le w_1 < w_2 \tag{8}$$

where N_l is the set of neighbors that interfere with the transmissions on link *i*. CH(i) represents the channel assigned for node *i*'s transmission and prev(i) represents the previous hop of node *i* along the path p.

As we have said, MIC not only takes the inter-flow interference into account but cope with the problem about the non-isotonicity in WCETT. It shows a better performance in the NS2 simulation. However, there are still three limitations in MIC. One limitation is the second component (CSC) captures intra-flow interference only in two consecutive links. Another limitation is that MIC factor-in the interference of a link caused by each interfering node in the neighborhood the same value, and counts the amount of interferers on a link only by the position of the interfering nodes no matter whether they are involved in any transmission simultaneously with that link. In view of this unique limitation of MIC, iAWARE utilizes the measurement of signal power to capture inter-flow and intra-flow interference and improves MIC. The third is that MIC is also non-isotonic because of the second component (CSC), and the author demonstrates somewhat more complicated ways that the nodes are decomposed into virtual nodes to make the metric isotonic.

4)MULTI-CHANNEL ROUTING PROTOCOL(MCR):The proposed MCR [21], [22] metric is on the basis of WCETT metric, combining with the switching costs of links over a path. MCR for a path is defined as follows:

$$MCR = (1-\beta) \times \sum_{i=1}^{n} (ETT_i + SC(c_i)) + \beta \times \max_{1 \le j \le c} X_j \tag{9}$$

where β is a tunable parameter subject to $0 \le \beta \le 1$, n is the number of hops on the path, X_j is the total ETT cost on any channel j, and total number of available channels is c. The additional component, Switching Cost j $(SC(j))$ is defined as follows:

$$p_s(j) = \sum_{\forall i \ne j}^{n} InterfaceUsage(i) \tag{10}$$

$$SC(j) = p_s(j) \times switchingDelay \tag{11}$$

where *InterfaceUsage(j)* is an exponentially weighted average for any channel j to measure what fraction of a second time interval a switchable interface was transmitting on channel j. This value does not figure in the time interval that this interface is tuned to channel j, but is idle. $p_s(j)$ is the probability that the switchable interface will be on a different channel (i j) when a packet arrives on channel j. *SwitchingDelay* is the interface switching latency, which can be measured offline.

HMCP [23]-[25] is the multi-channel link layer protocol matching with a corresponding multi-channel routing protocol, including this dedicated path metric MIC. When a sender transmits a packet to a receiver, it firstly tunes its switchable interface to the same channel as the receiver's fixed channel. So，the probability to use channel j over a link only needs to compute that of the sender side.

An obvious and unique advantage of MCR is that it introduces channel-switching cost into the routing metric;

thereby it can incorporate with the routing protocol like DSR, AODV for multi-channel and channel-switchable wireless network.

One serious disadvantage of this metric, similar to WCETT, fails to figure in the inter-flow interference although it is assumed all available channels are orthogonal. We still have some questions. Firstly, whether the same weight of the two components, SC and ETT, can contribute better performance to fine the "best" path. Secondly, whether $p_s(j)$ is an ergotic stochastic process still deserves to discuss before using this quality in the calculation of $p_s(j)$.

5)INTERFERENCE AWARE ROUTING METRIC (iAWARE):As far as we know, iAWARE [26] is the first routing metric for multi-radio WMN to factor-in both inter-flow and intra-flow interference and characterized by the physical interference model. In this model, a communication between nodes on a link ($u \rightarrow v$) is successful if the SINR (Signal to Interference Noise Ratio) at the receiver v is above a certain threshold. Let $P_v(u)$ denote the signal strength of a packet from node u to node v. So, formally demonstrating this model that a packet transmitted by u is correctly received by v if and only if:

$$P_v(u)/(N+\sum_{w \in V'} P_v(w)) \geq \beta \quad (12)$$

where N is the background noise, V' is the set of nodes simultaneously transmitting while the packet is transmitting on the link ($u \rightarrow v$) and β is a constant depending on the data rate, channel characteristics and modulation scheme etc. Then, we define that if $e_1 = (u,v)$ has conflicts with the link $e_2 = (u,v)$, any one of the following inequalities is true:

$$\frac{P_u(v)}{N+\sum_{w\in(x,y)} P_u(w)} < \beta, \frac{P_v(u)}{N+\sum_{w\in(u,v)} P_v(w)} < \beta$$
$$\frac{P_x(y)}{N+\sum_{w\in(u,v)} P_x(w)} < \beta, \frac{P_y(x)}{N+\sum_{w\in(u,v)} P_y(w)} < \beta \quad (13)$$

A link metric $iAWARE_i$ of a link i is defined as follows:

$$iAWARE_i = ETT_i / IR_i \quad (14)$$

where ETT of a link i is defined in WCETT, and Interference Ratio IR_i for a link i is defined based on the interference ratio $IR_i(u)$ for a node u on a link $i=(u,v)$ and $IR_i(v)$: $IR_i = \min(IR_i(u), IR_i(v)) \quad (0 < IR_i(u) \leq 1)$ in view of a bidirectional communication on a link i= (u,v). And $IR_i(u)$ is defined as follows:

$$\begin{aligned} &IR_i(u) = SINR_i(u)/SNR_i(u) \quad where \\ &SNR_i(u) = P_u(v)/N, \\ &SINR_i(u) = P_u(v)(N+\sum_{\omega\in\eta(u)-v} \tau(w) P_u(w)). \end{aligned} \quad (15)$$

Note that $\eta(u)$ denotes the set of nodes from which node u can hear (or sense) a packet and $\tau(w)$ is the normalized rate at which node w generates traffic averaged over a period of time. Then, $iAWARE(p)$ of a path p is defined as follows:

$$iAWARE(p) = (1-\alpha)\times\sum_{i=1}^{n} iAWARE_i + \alpha \times \max_{1\leq j\leq k} X_j \quad (16)$$
$$where\ X_j = \sum_{conflicting\ links\ i\ on\ channel\ j} iAWARE_i, 1 \leq j \leq k,$$

and α is tunable parameter subject to $0 \leq \alpha \leq 1$.

In a conclusion, iAWARE has two components, one for finding paths with less whole path cost and the other for exploiting channel diversity and finding paths with less intra-flow interference. Moreover, the introduction of SINR is a great breakthrough for inter-flow interference-aware routing compared with other ETX-based metric, like MIC, MCR, not to mention the aggregated ETX and WCETT.

Although it overcomes a considerable pitfall of the previous routing metric, iAWARE has its own weak points. One is that it is still a non-isotonic routing metric as WCETT, MCR. Furthermore, it fails to consider the cost of channel-switching delay characterized by MCR. If we attempt to take this cost into account, it may be more complicated than in MCR because MUP [27] cooperating with iAWARE utilizes RTT to find preferable channels for a link communication and all available channels are assigned stationarily to all interfaces of nodes. So far, how to combine the switching delay into iAWARE metric is still challenging.

B. Modified ETX

In the previous subsection, we discuss ETX and ETX-based routing metrics and mention these metrics perform poorly with short-term channel variations because the mean loss ratios fail to reflect the cost of high burst loss conditions. In this subsection, a routing metric modified on ETX, called mETX [28], corrects this shortcoming.

Firstly, we assume $P_{B,t}$ denoted the probability that a bit transmitted at time t is misdetected by the intended receiver wherein a time-varying binary symmetric channel; $\{P_{B,t}, t \geq 1\}$ denotes a stationary random process that is independent of the channel input. Then, let us define the discrete time process $\{P_{c,t}, t \geq 1\}$ as follows:

$$P_{c,k} = \prod_{t=t_k}^{t_k+S-1} (1-P_{B,t}) \quad (17)$$

where S denotes the bits of fixed-sized packets, t_k is the starting time of the transmission of the kth packet no matter whether it is a initial transmission or a retransmission. Finally, we define the mETX as $E[1/P_{c,t}]$, $mETX = \exp(\mu_\Sigma + \frac{1}{2}\delta_\Sigma^2)$

where μ_Σ and σ_Σ^2 represent the average and the variability of the error probability respectively. These two parameters, μ_Σ and σ_Σ^2 , are estimated statistically by $\hat{\mu}_\Sigma$ and $\hat{\sigma}_\Sigma^2$, considering the locations of erred bits in each probe packet and utilizing a loss rate sample calculated every ten seconds as said in ETX. Then, the mETX can be calculated using $\hat{\mu}_\Sigma$ and $\hat{\sigma}_\Sigma^2$.

This routing metric considering channel time-varying conditions is on the basis of ETX, so largely inherits the advantages of it, which means we can replace ETX with mETX in most of the ETX-based routing metrics, such as WCETT, MCR, in WMN in the future work. On the other hand, if we use the aggregated mETX of links on a path, it can only adapt to single-channel WMN.

C. Other Metrics

In this section, four routing metrics are discussed: the first two metrics, RTT and Per-hop Packet Pair Delay (PktPair), is link-quality metrics as ETX and mETX; the other two, Contention Node (CN) and B_{agg}, are traffic-aware metrics due to node contention measurement. In WMN, these routing metrics are neither used so widely as ETX nor modified for complicated multi-hop wireless network, so we just pay less attention to them.

1)RTT:This metric [27], [29] is utilized by MUP to choose the "best" channel for each link. To calculate RTT, a node sends a probe packet with a timestamp to each of its neighbors (a typical value is 500 ms). Once each neighbor receives the probe, it immediately responses with a probe acknowledgement, echoing the timestamp. Then, the node measures the round trip delay to each of its neighbors and keeps an EWMA of the RTT samples to each of its neighbors. The routing algorithm selects the path with the least total sum of RTT.

A high RTT implicates that the node or the neighbor is busy; otherwise other nodes in the vicinity are busy due to channel contention. Meanwhile, if probe or probe-ack packets are frequently lost, the 802.11 ARQ mechanism will retransmit the lost packets, and thereby the packet round trip delays increase, causing again high RTT. In a conclusion, selecting routes with the lowest aggregated RTT can avoid highly loaded or lossy links.

There are several obvious disadvantages of RTT. Firstly, its self-interference caused by queuing delay significantly distorts the RTT itself on links. Secondly, measuring RTT on links brings additional network overhead. Meanwhile, RTT, like ETX, does not explicitly factor-in data rate.

2)Per-hop Packet Pair Delay (PktPair): PktPair [30] is an improvement on RTT by correcting the problem of distortion of RTT on account of queuing delay. To calculate it, a node sends two probe packets back-to-back to each of its neighbor every few seconds (typically 2 seconds). The first probe packet is small while the second is large. The typical values are 137 bits and 1137 bits respectively. Each neighbor received the probes calculates the delay between the receipt of these two probes. Then, it reports this delay to the sender. The send, as in RTT, maintains the EWMA of PktPair values. The PktPair algorithm for a path is the sum of PktPair on links along the path.

This link-quality metric solves the main problem of RTT by eliminating the queuing delay of probe packets in metric values since each pair of probe delays equally. In addition, this metric has been used in WCETT on estimating the bandwidth because the second larger probe of each pair is sensitive to the link bandwidth. Although the accuracy of packet-pair estimations is lower as the channel data rate higher, PktPair technique sufficiently distinguishes various channel bandwidths.

PktPair has the similar limitations like ETX and RTT. It fails to take the data rate of links into account and is subject to network aggregated overhead even greater than in RTT and ETX. Meanwhile, it still suffers self-interference, but less severely than in RTT. Both RTT and PktPair have a worse performance than ETX due to load-sensitive, which is tested in [29].

3)Contention Node(CN) and Aggregated Traffic Bandwidth(B_{agg}):CN and B_{agg} proposed in [31] are characteristic of node contention measurement. The author divides neighbors into four types: a tx-neighbor, a rx-neighbor, a tx/rx-neighbor and a null-neighbor. A tx-neighbor of a node is a neighbor with a packet to send to it. A rx-neighbor of a node is a neighbor this node have a packet to send to. A tx/rx-neighbor of a node is a neighbor that is tx-neighbor as well as rx-neighbor of this node. A null-neighbor of a node is opposite of a tx/rx-neighbor, having no data packet to send to or receive from this node.

The contention nodes of a node are its neighbors with at least one rx-neighbor and tx-neighbors of its neighbors. The CN-based routing protocol counts the number of contention nodes of each node and calculates the sum of CN of nodes along the path for path discovery. The B_{agg}–based routing protocol computes the summation of the total bandwidth of contention nodes along a path. Each node keeps its neighbors' information about their types and bandwidths in a table. This table is updated by Hello messages transmitted by each neighbor every 5s. The values of CN and B_{agg} on the basis of the neighbors' information are calculated every 6.5s in the paper.

These two routing metric were proposed to improve WMN capacity by considering explicitly node contention. However, there are several problems needed to be discussed. One is that the values of both CN and B_{agg} only reflect the medium contention of the moments Hello messages are being transmitted. However, at other time during each Hello messages, metric performances are degraded. Another is that medium contentions caused by CNs are not supposed to be the same, nor just dependent on the bandwidth of CNs. Moreover, it claimed these two metrics outperformed ETX through NS2 simulation. However, in ETX [17], the information updated by Hello message is expected to renew every 1s while in [31] it is 15s. It is obvious that, in [31] the information update rate of ETX was unreasonably changed to be much slower than that of CN and B_{agg}. Thus, the simulation results of CN and B_{agg} are doubtful.

IV. Conclusion

In this paper, we addressed the problem of selecting effective paths in WMN, especially in multi-channel scenarios. Since most routing proposals, like AODV, DSR, are designed traditionally to find minimum hop paths, which usually results in poor performance, this paper presented a comprehensive review and a comparison of 10 kinds of routing metrics designed for diverse QoS requirements in WMN. Meanwhile, this paper classified these routing metrics into three basic types, ETX-based metrics, mETX, and some other metrics less attractive to WMN routing layer design.

We believe in the future work of optimal routing metric design, physical layer parameters, like SNR, SINR, will frequently appear in the metric schemes along with the development of hardware measuring these parameters. Also, as a modified edition of ETX, mETX can conduct a more effective estimation of link quality especially in time-varying conditions. Thus, mETX can take the place of ETX in unstable WMNs and achieve a higher network throughput. In addition, as multi-channel WMN are available for minimizing interference between links, the relevant factors, such as cost of channel switching delay, should be taken into account in the future routing metric design.

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