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Critical Insight into Design of Routing Metrics in Wireless Mesh Networks (WMNs)

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Abstract— **The increasing demand for communication elsewhere and also guaranteed QoS have led to the emergence of easily deployable, versatile and inexpensive next generation technologies. Wireless mesh networks (WMNs) have been envisaged as an essential network architecture for the next generation wireless networking. WMNs have emerged as one solution to extend the network coverage in multi-hop communication network. Mesh networks provide the advantage of working without the need of an infrastructure. However, routing in multi-hop wireless mesh networks is a complex research subject owing to the various issues in simultaneous transmissions, e.g., interference, self-interference, etc. Furthermore, the existing routing metrics assume that all applications running in the internet have the same requirement ignoring the fact that different applications have different characteristics. In this paper, wireless mesh networks have been discussed together with their potential applications. The existing routing protocols used in WMNs and the routing metrics which form the basis of these protocols, have been deliberated upon. Moreover, the pros and cons of routing metrics have been mentioned explicitly which should be considered in designing routing metrics to improve the network performance in future discourse.**

Index Terms—**Ad hoc networks, Routing Metrics, Routing Protocols, Wireless Mesh Networks**

I. Introduction

With rapid improvements in wireless local area networks and the cellular networks, wireless communication has undoubtedly been a desired service. A vast number of applications have been made available by the cooperation of these two technologies when they are put up together in terms of their requirements. Presently, wireless mobile networks exist in two different variations [1], one is called the infrastructure network which has wired, fixed gateways and the bridges in these networks are referred to as base stations. The general application of such a network may include the office Wireless Local Area Network (WLAN). Another type of network is known as the infrastructure less network which is also called self-organizing network. Such a network comprises of radio nodes that are mobile and do not require central management system or an existent infrastructure. These networks are applicable in the conditions when there is an instantaneous need of an infrastructure.

The next generation technologies shall offer flexibility on sending/receiving levels on the whole, high data rates, low capacity and equipment cost of arriving at all the subscribers. In order to solve all the problems arising at that point, a new concept has emerged namely the Wireless Mesh Network (WMN). It is an emergent technology in the field of next generation mobile networks [2].

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A wireless mesh network is a special kind of multi-hop wireless network that comprises of mesh routers and mesh clients [3]. Typically, mesh routers are stationary and have no power constraint. These routers form the wireless backbone for the WMNs while connected to the wired infrastructure. In this way, WMNs mesh routers provide the multi-hop wireless internet access to the mesh clients. However, mesh clients may be mobile and get internet access directly by forming a mesh with each other via the mesh routers.

In wireless mesh networks, several issues arise because of the huge number of nodes such as scalability, security, manageability which have to be dealt with. Therefore, the vast applications of WMNs make it necessary to provide security mechanisms and secrecy. The most important problem of wireless mesh network technology is its complexity. Though it is easy to design, deploy and transmit the packets, it is extremely difficult to attain optimum performance for providing robustness and security [2]. A typical example of wireless mesh network is shown in Fig. 1.

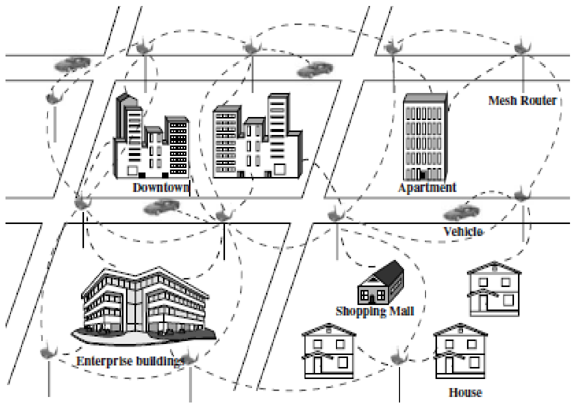

Figure 1 A Wireless Mesh Network (*Adopted from* [2])

The present 802.11 wireless local area networks (WLAN) rely on wired infrastructure to carry the user's traffics. However, this dependency on wired infrastructure is costly and inflexible as WLAN coverage cannot be extended beyond the back-haul deployment. WLANs can extend its capability using the mesh concept. Consequently, wireless mesh networks (WMNs) hold the promise of a solution to the coverage problem. However, the performance of a WMN is fundamentally dependent on the design of the routing protocols and the corresponding routing metrics. The routing protocols select the best route between the source and destination based on the routing metrics. Existing routing protocols used in WMNs rely on the IP layer and use hop count to enable multi-hop communication. Nevertheless, these protocols do not provide the solution to the inherent problem of wireless networks like interference, packet loss, and variable data rate. To overcome this, in 2004, IEEE formed a task group called IEEE 802.11s to develop an integrated mesh networking solution. After more than 7 years of efforts, in 2011, the IEEE published the 802.11 amendment for mesh networking, 802.11s [4]. This amendment set Hybrid Wireless Mesh Protocol (HWMP) as default routing protocol at MAC layer and Airtime Link Metric (ALM) as the default routing metrics.

The paper is organized as follows: Section II has discussed the characteristics of WMNs followed by their applications in Section III. Then, a description of the various routing protocols used in WMNs has been given in Section IV. Section V is dedicated to the discussion on routing metrics presently used by WMNs together with their advantages and disadvantages. The challenges that the existing design of routing metrics pose have been disseminated in Section VI after which the concluding remarks have been given in Section VII.

II. Characteristics of Wireless Mesh Networks

The major characteristic features of Wireless Mesh Networks have been enlisted below:

- They provide minimization of packet loss rate when sending packets through multiple nodes for solving line-of-sight problem particularly in centralized wireless networks.
- Wireless Mesh Networks can be enlarged and narrowed down very conveniently, thus networks can be added or subtracted easily even after network deployment thereby providing unlimited coverage.
- WMNs provide accessibility to diverse network environments as well as peer-to-peer network functionality.
- In wireless mesh networks, energy efficiency is not a top priority as they do not have energy consumption constraints.
- WMNs comply with the existing wireless network technologies since they are in accordance with IEEE 802.11 technology.
- Mesh networks ensure to provide functionalities like routing, power control, management and security.

Thus, WMN is not just simply another adhoc network but it diversifies the effective capabilities of adhoc networks. The additional features that the wireless mesh networks offer demand the design of new principles and algorithms for realizing WMNs [5] [6].

III. Applications of Wireless Mesh Networks

Wireless Mesh Network is a fast-growing wireless technology. WMNs can meet the needs of multiple applications [7]. Wireless network applications have many dead points as they stand. Coverage of broadband home network which is set by WMN can be decreased without using additional physical hardware. To improve the coverage, changing the positions of mesh routers or just adjusting the signal power is enough. Ad hoc and wireless sensor networks are not appropriate to support such applications. WMNs are ideal in this case due to their load balancing property [2].

Due to the high performance and flexibility of WMNs, many applications are feasible for these kinds of networks. Various examples of WMN applications can be specified as Cellular or WLAN hotspot multi-hopping, Community networking, Home and office indoor networking, Micro base station backhaul, Vehicular Ad hoc Networks (VANETs), Wireless Sensor Networks (WSNs) [8]. Some other examples are:

- Emergency networks

In the case of natural disaster like earthquakes, communication and power system may be destroyed. A mobile communication device use by the emergency team covers small range and performances are strongly constrained by their battery power. Wireless mesh networks can provide benefits of both larger coverage area and better performance, even allowing video streaming by forming mesh with stationary mesh routers equipped with a strong battery together with lightweight client. In addition, the self healing and auto configuration makes the network easily extendable.

- Industrial organizations

Wireless mesh networks are ideal solution to facilate heavy industrial operations and sites such as coal mine, oil and gas fields and construction areas, which are difficult to network using wire or traditional WLAN because of their geography. With the use of WMN, field workers can communicate easily and have access to key applications.

- Community networks

Neighbourhood community networks can be formed by sharing the single broadband internet connection. Also distributed storage and data exchange can be made easily among the users. This network is also easily extendable by deploying more mesh router.

- Building automation

Today's smart buildings deploy many sensor systems which need to be networked. This can be achieved by deploying the mesh routers to some strategic location and incorporate it with other networks such as existing Ethernet-parts, WSAN or cellular networks.

- Broadband wireless internet access

To provide broadband internet facility in a rural area, WMNs can be easily deployed. Using the existing power lines, mesh router can be setup. In case of increasing demand, the network may be expanded step-by-step with more mesh routers.

IV. Routing Protocols In Wireless Mesh Networks

In the context of wireless communication and networks, routing or path selection is the mechanism of selecting the best path from source to destination. Each router maintains at least a routing table which is a data structure that stores next hop and the cost towards the destination. The set of algorithms and procedures that are used to build the routing tables are called routing protocols.

Routing is an intricate problem and essentially a major issue in any networking architecture. In internet, routing protocols are divided into two categories: intra-domain (within an autonomous system) and inter-domain (used to connect autonomous systems).

Both inter-domain and intra-domain routing protocols are scaled well for internet because internet is primarily a wired infrastructure. However, the inherent broadcast nature of the wireless medium at physical layer imposes many constraints like transmission between neighbours is affected with other nodes in their proximity. Also, periodic or frequent route updates in large networks may consume significant part of the available bandwidth, increase channel contention and so on. To overcome these problems, Internet Engineering Task Force (IETF) MANETs group proposed a number of routing protocols for ad-hoc network. The design of routing protocol and the associated routing metric have a significant effect on the performance of a WMN.

Most of the WMN protocols make use of comparable strategies which have been adopted from adhoc networks. WMNs can be classified in four categories viz., controlled flooding, adhoc based, opportunistic and traffic aware (or tree based) protocols [9]. These classes differ on the basis of maintenance procedures and route discovery. In wireless mesh networks, it is considered by routing protocols that there are only wireless back-bone nodes in the network. In due course of time, if it happens that a mobile device functions as backbone node, then it has to run on the same protocol [10].

A. Ad-hoc Based WMN Routing Protocols

These protocols deal with the variations in link quality by adapting ad-hoc routing protocols. There is progressive updation of link metrics by routers and then they are disseminated to other routers, e.g., Link Quality Source Routing (LQSR) protocol, SrcRR, Multi Radio LQSR (MR-LQSR).

B. Controlled Flooding WMN Routing Protocols

These protocols are designed to minimize control cost. In case of temporal flooding, frequency is defined as per the distance to router. Further, by making use of spatial flooding, the nodes at far obtain lesser information from the source. The central idea is the inefficiency of the flooding network since a number of connections occur between close nodes in wireless networks, e.g., Localized On-Demand Link State (LOLS), Mobile Mesh Routing Protocol (MMRP), and Optimized Link State Routing (OLSR).

C. Traffic-Aware WMN Routing Protocols

These protocols take into account the general traffic matrix of wireless mesh networks [9], e.g., Ad-hoc on demand distance vector-spanning tree (AODV-ST).

D. Opportunistic WMN Routing Protocols

These protocols support routing on the basis of cooperative variety schemes. These protocols implement successful link layer retransmission in the instance of link failure and continue until the next hop reaches the neighbor successfully or till number of link layer retransmission reaches to its maximum. This protocol guarantees data transmission to a destination which can be at least one hop away, e.g., Extremely Opportunistic Routing (ExOR) protocol, Resilient Opportunistic Mesh Routing Protocol (ROMER).

Based on the routing information dissemination and path discovery process, these protocols can be classified as proactive, reactive and hybrid.

In proactive routing, a routing path is established between two nodes prior to any transmission of data traffic. To maintain the routing table up to date, a node periodically sends control information which may cause wastage of valuable bandwidth. However, to keep every nodes' routing tables updated, a large amount of communication overhead is generated. Examples of proactive routing protocols are: Optimized Link State Routing protocol (OLSR), Destination-Sequenced Distance Vector routing protocol (DSDV) and Wireless Routing Protocol (WRP).

In reactive routing protocols, a path is established only when the source needs to communicate with a destination. This certainly reduces the routing overhead but introduces a route setup delay. A number of different reactive routing protocols have been proposed to increase the performance of reactive routing such as Dynamic Source Routing protocol (DSR), Ad hoc On-demand Distance Vector (AODV) and the Dynamic MANET On-demand (DYMO).

Hybrid routing protocols integrate both reactive and proactive routing feature to enhance the overall scalability of routing in networks. Many hybrid routing protocols have been proposed to enhance the routing protocols performance such as Zone Routing Protocol (ZRP), Zone-based Hierarchical Link State (ZHLS) and Distributed Spanning Trees based routing protocol (DST). Nevertheless, the aforementioned routing protocols used in WMNs depend on the IP layer (layer 3) to provide multi-hop communication and cannot capture the nature of the wireless link accurately [11]. As wireless medium is more vulnerable compared to wired medium, a multi-hop routing protocol must account for the nature of the wireless links to operate in a wireless environment. To realize the benefits of MAC-based WMN routing, hybrid wireless mesh protocol (HWMP) and air time metrics are proposed by IEEE 802.11s. HWMP is a hybrid routing protocol of on demand (reactive) routing and proactive tree base routing.

One alternative paradigm which became popular to broadly classify routing protocols for WMNs is based on which layer the protocols work at: layer 3, layer 2.5 and layer 2 [12]. Traditionally, in internet and mobile ad-hoc networks, the routing protocols work in layer 3. WMNs also often reuse these protocols, mainly AODV and OLSR by the use of the IP networking stack. The most obvious advantage of this approach is that WMNs can be readily deployed by exploiting the currently available hardware and software used in wireless communication. However, this has many implications. Firstly, each mesh node should have the IP stack, which could be undesirable, particularly when MSs are realized with Access Points. Moreover, a tight integration between layer three and two is necessary to provide QoS which in fact is very complex to design. Consequently, optimization cannot be achieved.

In layer 2.5 approach, WMN appeared as a common layer-2 link (e.g., Ethernet) which is transparent to the IP networking stack and by imposing a specific entity between layer 3 and layer 2. The most important benefit of meshing at layer 2.5 is that the available layer three (and above) software can work without any modification. However, additional encapsulation as well as protocol overhead is introduced by this approach that degrades the network performance.

The third strategy of WMNs architecture is to integrate the mesh functionalities at layer two directly. The IEEE TGs has taken this approach. This approach also makes the mesh unseen to higher layer protocols. However, it may provide better performance than layer 3 and layer 2.5 because of the closer interface with the physical device. But inherently, layer two addresses are not hierarchical. Consequently, MAC-based forwarding tables are not scalable as IP routing tables. Nevertheless, layer two WMNs are generally deployed for small-scale applications; with limited number of mesh nodes (e.g., up to 32 MSs in the IEEE 802.11s standard).

V. ROUTING METRICS IN WIRELESS MESH NETWORKS

A routing metric is a parameter, value or weight associated with a link or path, based on which routing paths are decided by a routing algorithm. Designing routing metrics is of much significance due to the limited channel bandwidth in wireless communication [13]. Thus routing metrics have a significant role in the performance of a routing protocol. Different types of routing metrics are used in a routing protocol to achieve different optimization goal. Several routing metrics have been designed for efficient sharing of radio resources in wireless mesh networks. Though a lot of research studies have been conducted foe comparing the performances of the current routing metrics, there is no fitting study that provides precise explanation of the difference between these metrics. The current routing metrics can be categorized in the following types: distance, traffic load, channel usage, error rate, latency, compositive metric and multiple channel. Typical examples of these metrics have been given below:

A. Distance routing metric

Hop count: Hop-count metric takes into consideration number of hops in between source and destination. Therefore, this metric gives us the route with minimum distance. In adhoc networks, hop-count is quite popular as it makes use of route length as a criterion thereby providing simple computation and has low routing overhead. Nevertheless, it does not take into account other issues like transmission rate and provides very little information about the quality of a link, such as packet loss, interference, etc due to its on/off feature which are vital for taking routing decision of any wireless networks. Thus, hop-count based routing protocols only consider single performance parameter, i.e., the minimum number of hop in each route. Usually, minimization of number of hops is not the performance goal of WMNs, thus it may lead to poor performance. Furthermore, this metric does not take into account congestion which is produced when sharing a transmission medium and cannot perform successfully in particular wireless mediums.

B. Latency routing metrics

Per-hop Round Trip Time (RTT): This has been designed specifically for Multi-Radio Unification protocol [14]. Per-hop RTT captures the traffic load and delay between two nodes on a link as well as the contention status of all the neighbouring nodes. It is able to evade link loss and busy channel by the selection of selection. However, the contention among various nodes for low RTT link may lead to queue delay. RTT also results in self interference and high overhead. Moreover, Per-hop RTT is greatly varied with the traffic load or queuing delay. Consequently, the route may become unstable.

Per-hop Packet Pair Delay (***PktPair*** or ***PP***): It is an enhanced version of per-hop round-trip time (RTT) which takes into consideration transmission rates and queue delay [15]. Two subsequent probe packets are sent between the neighbours node to measure the Per-hop packet pair delay (PPD). The neighbour calculates the delay between these two packets. Then this information is sent back to the probing node [16]. This technique needs more probe packets which increases the routing overhead than per-hop RTT. In addition, per-hop PPD does not reflect end-to-end performance parameter rather it only reflects per-link performance parameters.

C. Traffic load routing metric

Neighbourhood Load Balancing **(*NLR*):** In NLR, the average load of every neighbourhood is measured in order to bypass the entire busy neighbourhood and not just the busy node with Load-count [17]. NLR takes into account three different aspects while selecting the best path i.e., neighbourhood interference, transmission bandwidth and IFQ length of every node, unlike the current routing metrics.

D. Error rate routing metric

Expected Transmission Count **(*ETX*):** This metric provides an estimation of expected number of MAC layer transmissions for wireless links and computes the packet loss rate proposed in [15] [18]. Thus, the link ETX accounts the effects of link quality as well as packet loss. The benefits of *ETX* are non self-interference and reduced probing overhead because it does not measure delay. Additionally, broadcast rather than unicast of the probe messages reduce the overhead. Moreover, ETX is an isotonic routing metric, which ensures uncomplicated calculation of minimum weight paths and loop-free routing under all routing protocols. However, ETX has several shortcomings. Firstly, ETX is a routing metric for single-channel multi-hop wireless network which does not consider different links may have different data rates. Secondly, it does not correctly reflect loss rate of actual data traffic because probe messages are transmitted by lower transmission rates with more robust modulation and coding techniques. Thirdly, the estimation method in ETX depends on the mean loss ratio. But, wireless links more often experience burst losses. In addition, ETX based route does not ensure load-balancing in the network. Notwithstanding the stated shortcomings, ETX metrics capture the network-wide performance by taking the per-link performance.

***Airtime link metric*:** Airtime link metric is the default path selection metric proposed by IEEE 802.11s, amendment of mesh networking [4] governs the routing prospect of every pair of nodes. This metric is used to select a competent radio-aware path amongst the multiple paths between source and destination. The airtime accounts the channel resources required for transmitting a frame by a particular link. This approximate measure is designed for ease of realization and interoperability. The major drawback in this metric is the generation of a high probing overhead.

E. Multi-channel routing metric

Weighted Cumulative ETT **(*WCETT*):** It has been proposed by [16] and it takes into account multi-radio nature of wireless mesh networks in two sections: the diversity of the channel in the path and overall transmission time along every hop in the network. Though it is capable to capture intra-flow interference of a path while computing assignment time of channel, inter-flow interference is not taken into consideration. Furthermore, there is no guarantee of shortest paths [19]. WCETT does not explicitly consider the effects of inter-flow interference which causes WCETT route flows to dense areas where congestion is more likely. Moreover, due to the second term of equation, WCETT is not isotonic and very difficult to calculate and used with link state protocol [10] [13].

F. Channel usage metric

Interference-Aware Routing Metric (***IAR***): *iAWARE* is a routing metrics to reflect both interflow and intraflow interference for multiradio WMN [20] [21]. This metric captures MAC layer information to sense the channel busy level. Smaller the value of IAR, lesser is the traffic in path. This metric uses SNR (Signal to Noise Ratio) and SINR (Signal to Interference and Noise Ratio) to continuously reproduce neighboring interference variations onto routing metrics [10]. *iAWARE* takes into account the effect of dissimilarity in link loss ratio, variable transmission rate. In addition, it also captures the interflow and intraflow interference. However, it is a non-isotonic routing metric.

G. Compositive metric

Weighted Cumulative ETT with Load Balancing **(*WCETT-LB*)**: This metric was presented by [22] which is a superior version of *WCETT.* It takes into consideration load balancing in the metric by involving the congestion level that is achieved after computing the average queue length on every node. Nevertheless, *WCETT-LB* has the same limitation as *WCETT*.

Some other routing metrics used in wireless mesh networks have been given below:

Cross-layer approaches: Special attention is being paid to these approaches in WMNs [23]. Using multiple channels has become quite common amid the various techniques available. Multiple channels make it possible to increase the network throughput owing to the simultaneous use of non-overlapping channels available which have been defined in IEEE 802.11. However, in order to enhance the effectiveness of this technique, two issues have to be dealt with which are inter-flow and intra-flow interference. The intra-flow interference arises when diverse nodes which transmit packets from the same flow intervene with one another. On the other hand, the inter-flow interference occurs during concurrent flows.

Effective Number of Transmissions (ENT): These metrics were proposed by [20]. They take into consideration average values of link quality besides standard deviation in order to reflect physical-layer variations on the metrics. ENT enhances the accuracy of the link quality estimation used to derive ETX of a link and adding the quality-aware routing. Nevertheless, the drawbacks of ETX are inherently prevailing in the estimation of ENT.

Expected Transmission Time (ETT): This metric is designed by the addition of bandwidth to ETX. ETT is an improved version of ETX because it involves bandwidth in its computation as well [18]. The ETT metric reflects the effects of packet size and link bandwidth on the performance of the path. So ETT eventually improves the throughput of path by measuring the link bandwidth and would enhance the overall performance of the network. Nevertheless, ETT is not designed for multi-radio network and does not minimize the intra-flow or inter-flow interference in the network [24].

Metric of Interference and Channel- Switching (MIC): This metric is proposed as an improvement over WCETT as it captures additional information on the link shared [18]. Metric of Interference and Channel-Switching (MIC) has been designed to reflect on both inter-flow plus intra-flow interference [25]. When this metric is implemented, it shows several major limitations [26]. Firstly, it adds significant overhead due to updation of ETT for every link which may degrade the performance of the network significantly depending on the traffic loads. Secondly, it is assumed that the level of interference contributed by every link in the collision domain is the same regardless of the variations in traffic load at every node.

Link Type Aware (LTA): Wireless mesh networks architecture is taken into consideration to calculate the Link Type Aware (LTA) metric [27]. To calculate this metric, three types of links are considered. These are: the link between two mesh routers which is reliable, link between two mesh clients which is unreliable and link between mesh router and mesh client which is half-reliable. The LTA metric selects reliable path for transmission of data and reduce link broken time in typical scenario. However, link quality or interference is not considered for calculation of LTA.

Expected Forwarded Delay (EFD)**:** Expected Forwarding Delay calculates the forwarding time of a packet of specific traffic class in a node [28]. The protocol then chooses the route that has the least cumulative EFD.

Integrating Multiple Metrics (IMM)**:** This metric was proposed after combining ETX, RTT and Hop Count, and incorporating it into AODV which improves the packet delivery ratio, throughput plus end to end delay of the protocol [29]. However, the above mentioned metrics account link layer parameter indirectly through a method in the upper (network) layer and do not consider the different characteristics of the different applications.

Fuzzy Link Cost metrics (FLC): Fuzzy Link Cost metrics (FLC) use dynamic selection of metrics as well as a fuzzy link cost (FLC) to select the best path for multimedia packets. This fuzzy system is derived from ETX of a link and minimum delay (MD) between the links. However, this metrics does not consider the link bandwidth which is very important especially for multichannel wireless radio [30].

The current routing metrics used for routing in WMNs can also be categorized on the basis of protocol layers which these metrics use for their operation. Routing metrics can thus be: single performance parameter metric, multi-protocol layer metric for multiple performance parameters and single protocol layer metric for multiple performance parameters.

In this regard, Load-count and Hop-count are network layer routing metrics i.e., these capture either traffic load or number of hops along the path. Therefore, these metrics are grouped under single performance parameter metric. IAR is an example of multi-protocol layer routing metric for multiple performance parameters. It takes into account network layer as well as link layer for capturing packet size, bandwidth and MAC handshake time. Per-Hop RTT, Per-Hop PPD, ETX, ALM, WCETT, WCETT-LB are single-protocol-layer metrics for multiple performance parameters.

Table I Strengths and Limitations of Existing Routing Metrics

Name	Strength	Limitation
Hop Count	• Simple, easy to implement and low routing overhead	• Does not consider link bandwidth, packet loss and network load
Per-Hop RTT[14]	• Avoids highly loaded or lossy links	• High overhead. • Accuracy depends on traffic load
Per-Hop PPD[14]	• Less impact by traffic load	• High overhead then RTT • No load balancing
ETX[18]	• Capture packet loss and retransmission contention	• Does not consider link bandwidth. • Can have bottleneck link
ENT[20]	• Capture end to end packet loss	• High overhead. • Also it does not consider link bandwidth
ETT[24]	• Improve ETX by considering link bandwidth.	• Does not consider intra-flow and inter-flow interference in the network
WCETT[16]	• Improve ETT by considering intra-flow interference	• Not applicable to single radio multichannel WMN
MIC[25]	• Capture both inter-flow and intra-flow interferences with load balancing capability • Support multichannel operation	• High overhead • Not isotonic and difficult to estimate interference level
LTA[27]	• Consider the infrastructural architecture of WMNs	• Does not consider the link quality and interference issues
ALM [4]	• Capture the impact of frame loss, link bandwidth and protocol overhead	• Not consider the application characteristics. • Queuing delay is not considered
EFD[28]	• Improve ALM by considering backof and queuing delay of different traffic class	• Does not consider application requirements.
IMM [29]	• Capture multiple performance parameters (hop count, ETX and RTT).	• Not consider the application characteristics
FLC [30]	• TCP and UDP packet routed differently using fuzzy logic which improves the network performance	• Does not consider interference. Also divide application only two broad categories which always not optimize the network performance

VI. Open Issues

According to Table I, there are still several remaining issues in the design of routing metrics for WMNs. Therefore, it is necessary to design new routing metrics to better optimize the routing protocol so as to achieve better performance.

- Numerous routing metrics have been developed for WMNs. However, most of the routing metrics used to get link layer performance parameter by implementing a method in the network layer which may not be accurate all the time. Moreover, these take into account only limited network parameters. Therefore, constraints like hop count, link delay, packet loss ratio, congestion and performance parameter like throughput, Quality of Service (QoS), scalability, load balancing, etc. need to be optimized for diverse applications. One routing metric may not be adequate to optimize under heterogeneous constraint and performance parameter. So, investigation is required to combine multiple metrics in a routing protocol.
- There are several routing metrics presently that are still working ad-hocly as a result of which they show good performance for specific types of WMNs only, say, a client WMN.
- The probe exchange based metrics viz., Per-Hop RTT, Per-Hop PPD, ETX, ALM, WCETT, WCETT-LB perceive routing status by transferring probes in group, cluster or the overall network and thus may produce huge overhead. These show a poor performance particularly for large scale networks.
- There occur some routing metrics which give an inaccurate measure of the routing status, e.g., ETX makes use of unicast for measuring the transmission error rate thus abusing broadcast wireless communication.
- In WMN, the routing protocols forward packets based on network layer address and using hop count or some link layer parameter as routing metrics. However, these link metrics have limited accuracy. MAC layer has more adequate knowledge about its neighborhood radio which is more accurate and up-to-date. So, it needs to examine which is the best technique for routing or path selection for wireless mesh network: MAC (layer 2) or IP (layer 3) or cross layer interaction.

VII. CONCLUSION

The paper formulates an elaborated discussion on the routing in wireless mesh networks. A study of several routing protocols and routing metrics has been performed with a view to point out the drawbacks in the design of routing metrics. It has been observed that the performance of routing protocols very much depends on the routing metrics used by the protocol to make routing decisions. Deducing from the list of limitations found in existing routing metrics used in literature, it is recommended that novel routing metrics should be designed that take into consideration the combination of link bandwidth, frame loss, delay of the link and concurrently giving priority to the metrics according to application type.

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