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A Study on Link Quality, Load and Energy Aware Routing Metrics in Wireless Mesh Network

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Abstract: Wireless Mesh Network is an emerging technology due to their advanced features like low deployment cost, last mile broadband connectivity and easy to installation. Routing in Wireless Mesh Networks is a hot research topic in recent years, with the goal to achieve high throughput and reliable routing over the network. Routing protocols play a vital role in routing. They are divided into three categories such as proactive(table-driven), reactive(on-demand) and hybrid. Proactive routing protocols compute routes between every node in the network irrespective of its usage whereas reactive protocols compute routes only when it is required for the transmission. Hybrid routing is a combination of proactive as well as reactive routing. Routing metric is a parameter used for selecting the best route between source and destination. The existing protocols use the hop count as the routing metric. However, the default hop count metric may generate congestion, node failure and link failure etc. Hence, many routing metrics have been proposed for wireless mesh networks by considering the quality or capacity of a link, load, transmission rate, bandwidth, distance, cost, energy etc. These proposed routing schemes provide high flexibility and reliability in the selection of best path between source and destination. In this paper, the proposed routing metrics which are created by considering the link quality, energy and load are discussed.

Keywords: link quality, energy, ILA, CWB, PIM.

I. INTRODUCTION

The recent development in wireless communication technologies has encouraged a flourish of a new kind of multi-hop wireless network architecture, called Wireless Mesh Networks (WMNs). Wireless Mesh Network is a communication network made up of radio nodes organized like a mesh topology. The architecture consists of mesh clients, mesh routers and gateways. The mesh clients are often stationery devices, laptops, mobile phones and other wireless devices. The mesh routers forward messages to and from the gateways and it also forwards the packets to remote nodes through another router located within a few hops. Gateway may connect to the Internet through a wired or wireless link. A mesh network is reliable and provides redundancy. When one node fails in the network, the rest of the nodes can communicate with each other, directly or through one or more intermediate nodes [1][2]. WMN possess the advanced features of robustness, wide area coverage, easy network deployment and maintenance, self-healing, self-configuring, low deployment cost and self-organizing etc. Due to these features, WMN is mainly used in Healthcare, Disaster recovery, Home Automation, Historical Monuments and Industries [3]. The WMN has the following important characteristics[4].

- It supports ad-hoc networking and has the features of self-configuring, self-healing and self-organization.
- WMN is a multi-hop wireless network; through mesh routers, it provides wireless infrastructure/backbone for mesh clients.
- The mesh routers are static and it performs dedicated routing and configuration to reduce the load of mesh clients and other end nodes.
- Mobility of mesh clients is supported easily through the wireless infrastructure.

- Mesh routers integrate different types of network access such as Wi-Fi, WiMAX, Sensor, Cellular etc in WMN.
- Power-consumption constraints are different for mesh routers and mesh clients.

The architecture of WMN can be categorized into the following three types [2]: Client, Infrastructure and Hybrid WMNs. Client WMN are simply a mobile ad-hoc network. An important feature of this type of WMN is, all the nodes in the network are mobile devices without a wireless backbone. The mobile devices are known as Mesh Clients. The Mesh Clients assume the responsibility of Mesh Routers to route and forward packets from one client to another and expand the overall range of the network beyond the physical single-hop range of individual nodes. In Infrastructure WMNs, the Mesh Routers (MR) form a wireless multi-hop backbone and it provides an end-to-end connectivity to Mesh Clients (MC). This type of WMN consists of static Mesh Routers. The Mesh Clients can communicate with each other though the Mesh Routers. Hybrid WMN is a combination of Infrastructure and Client WMN. Mesh Routers form a Mesh backbone infrastructure while Mesh Clients involve in the routing and forwarding of packets. Different type of communications can be established in Hybrid WMN. Mesh Clients within a client mesh can communicate directly. The Mesh Clients in one client mesh can communicate with mesh clients in another network via Mesh Routers. The Mesh Clients can communicate with Mesh Routers by discovering the appropriate mesh router to gain access to infrastructure part of the network.

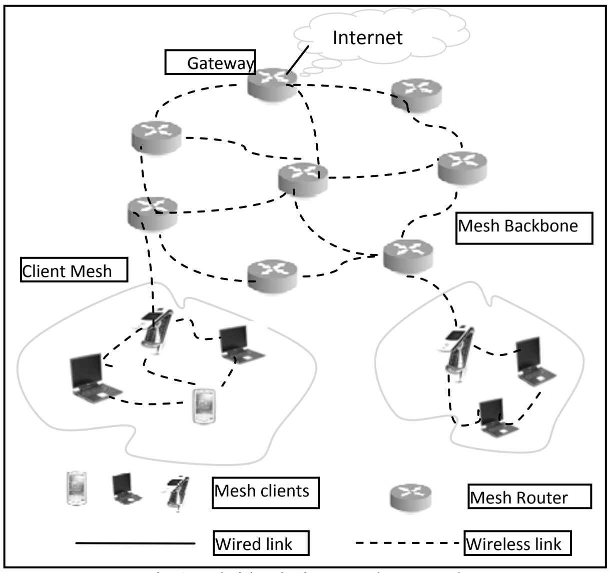

Fig.1 Hybrid Wireless Mesh Network

Routing is an important task for finding the route between source and destination. Finding the route is not a simple process, routing protocols place a vital role for performing this task. The routing protocols find a route based on certain routing metric. The existing routing protocols use hop count as the routing metric. Due to limitations of hop count metric in WMN, some routing metrics have been proposed to increase the throughput and reliability of the network. In this paper, the proposed metrics based on link quality, load and energy aware are discussed. The paper is organized as follows: Section 2 deals with the routing protocols; section 3 shows the routing metrics; section 4 discusses the proposed routing metrics in WMN. Section 5 presents the conclusion.

II. Routing Protocols

Routing protocols play a vital role for discovering a best route between source and destination. Various routing protocols are available in the ad-hoc network and these are classified into three types such as proactive (table-driven), reactive (on-demand) and hybrid.

A. Proactive

In proactive protocols[5][6] each node maintains a routing table, which contains routes to all the other nodes in the network. The routes are found and stored even if they are not needed. The number of tasks is carried out to maintain the recent routing information but it increases the considerable overhead and bandwidth consumption in the network. Destination Sequenced Distance Vector (DSDV)[7][8] routing protocol is an example for proactive routing protocol.

B. Reactive

Reactive protocols [5] take an indolent approach to routing. In contrast to proactive routing protocols all up-to-date routes are not maintained at every node, instead the routes are created as and when required. When a source wants to send message to a destination, it invokes the route discovery mechanism to find the route to the destination. The route remains valid until the destination is reachable or until the route is no longer needed. This approach is not suitable for operations that require immediate route availability as there is a delay for finding a route. Ad-hoc On Demand Distance Vector (AODV)[9] routing protocol is an example for reactive routing protocol.

C. Hybrid:

A typical hybrid routing protocol is the combination of proactive and reactive routing protocols. Zone Based Routing (ZBR)[10] protocol is an example of hybrid routing protocol. ZBR divides the network into different routing zones. The routing zone of node A includes all the nodes within the hop distance of utmost h from node A. The value h is the radius of the zone. The nodes which are exactly h are called the peripheral nodes of A's routing zone. The route discovery process is similar to that of Dynamic Source Routing (DSR)[11] but the RREQs are broadcasted only through the peripheral nodes. It proactively maintains the routes within the routing zones and reactively searches for routes to the destination which is outside of the node's routing zone. ZBR can be dynamically configured to a particular network by tuning the value h. ZBR act as only a proactive routing protocol when the value of h is the diameter of the network and act as only a reactive routing protocol when the value of h is zero[WEB10].

III. ROUTING METRICS

A routing metric is basically a value assigned to each route or node and it is used by the routing algorithm to select one or more routes out of a set of routes discovered by the routing protocol. These values actually reflect the cost of using a particular route with respect to some optimization objectives(minimum, maximum or average) by considering the application and network performance. In most cases, the metrics that are computed by one routing protocol are incompatible with those used by other routing protocols. In particular, the objective of the routing algorithm and thus the routing metric may be categorized into following factors[13]. The first three objectives are the application oriented whereas the last three affects the performance of the whole network.

Minimize Delay: According to this routing function, the route which has minimum delay is selected as a best route for delivering the packets to the destination.

Maximize the Ratio of data delivery: In most of the applications, the main requirement is to achieve a higher delivery ratio which means a low data loss rate along the network route, even it increases the delay.

Maximize Path throughput. In this routing process, the routing algorithm selects the route which has higher link capacity.

Maximize Network throughput. This objective can be carried out by maximizing data flow in the whole network with minimum interference and retransmissions.

Minimize Energy consumption. Energy consumption is main criteria in wireless networks where the nodes are mobile devices.

Balanced Traffic load. This objective is more common in all applications. The routing algorithm balances the traffic on the entire network by equalizing the load on each route.

Minimize Routing Overhead: This objective can be performed by selecting the best route throughout the network, so that it reduces the route discovery.

A. *Routing Parameters*

Routing protocols use routing parameters as a routing metric to choose a route from the source to the destination. Some protocols use a single parameter as metric while some advanced protocols use multiple parameters as a metric to choose a route. The routing parameters that are used as routing metrics in various routing protocols are:

- Hop
- Bandwidth
- Queue Length
- Energy
- Link Quality
- Cost
- Distance
- Transmission Rate
- Interference

Hop

Hop represents a portion of the path between source and destination. When communicating over the Internet, data passes through a number of intermediate devices (like routers or gateways) rather than flowing directly over a single wire. Each such device causes data to "hop" between one network connection and another. Next hop is a term used in the network and it represents the next router/gateway through which packets should be forwarded along the path to their final destination.

Bandwidth

The term bandwidth[12] refers to the amount of data that can be carried from one point to another in a given time period. It can be expressed in bits per second(bit/s) or multiples of it (For example, kbit/s, Mbit/s, Gbit/s, etc.). Routing protocols may use bandwidth to determine which link type is preferred over another. This bandwidth is also one of the routing metric to choose a path for the transmission. Higher bandwidth path always produces the best route for the transmission.

Queue Length

The queue is a buffer which is used by each node in the network for storing the waiting packets. When the packet arrives a node, it is sent to next hop node if it is free for receiving the packet, otherwise it stores the packet in the queue. Packet scheduling is used in the queue for choosing the packets to service or dropped during the simulation. Queue length always determines the current load of a node during the packet transmission. It is an important factor for solving the congestion and delay problems in the network.

Energy

Each node in the network has an initial energy value. It is an important factor for transmitting the packets from source to destination. The node depletes its energy during the transmission for sending as well as for receiving the packets.

Link Quality

Link quality is a main parameter, it is known as the link’s ability to support traffic density during the transmission of the network. The status of the link between two neighbours is affected by parameters like distance, battery power and mobility. The stability of the link can be determined by less bit errors and reach the destination with high signal strength.

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Cost

Cost is an integer value which is assigned to a node and determines the value of the node. Single factor or multiple factors combined to form a cost value. During the route selection process, the lowest cost node is selected for the transmission.

Distance

This parameter determines the distance between two nodes in the path. For better performance, the minimum distance path is selected for transmission.

Transmission Rate

Transmission Rate is the total amount of data that can be sent from one node to the other node in the network at a given period of time. This parameter also determines the best route by considering the higher transmission rate.

Interference

In wireless networking, signals operating at similar frequencies can cause interference with each other and have a significantly negative effect on the performance of the network. This means that more popularly used frequency bands such as the 2.4GHz unlicensed band can get severely affected by the overcrowding of wireless signals to a point where a device will not operate at an acceptable level. There are two types of interference; inter-flow interference refers to the interference between neighboring routers competing for the same busy channel whereas intra-flow interference refers to the interference between intermediate routers sharing the same flow path.

The above are routing parameters which can be used as a routing metric by the protocols for choosing the route from the source to the destination. The existing routing protocols use hop count as their default routing metric. Hop count[14] refers the number of intermediate devices (like routers) through which the data should pass from the source to the destination. This metric only considers the total number of hops between source and destination. Minimum hop count route always is the best route for the transmission. The past test bed experience[15] has demonstrated the difficulties of using hop count as a routing metric. Since this minimum hop count routes do not consider the quality of the link, the constructed routes frequently experience the weakness in the link. Thus, routing protocols spend a significant amount of time for reconstructing routes when one of the links in the routes fade or whenever a shorter but unreliable link is available in the route.

The default minimum hop count route also suffers from node failure due to its energy loss. The energy loss is happened when the route is constructed with minimum energy nodes. This minimum energy node always creates a node failure problem in the route since the node loses its energy very quickly when compared to other nodes. This causes the node to get disconnected from the route very quickly and it increases the route discovery latency. Another problem may arise in the selection of hop count metric is, it selects the route irrespective of its node's queue length. If more than one route having the same node for their transmission, it creates congestion and increases the delay of delivering the packets to the destination.

To avoid these types of difficulties, the route can be constructed with link quality, energy, load etc. Though this hop count metric is used in wireless networks, the energy, link quality, bandwidth, interference and etc give rise to more complex trade off. In addition to that, many routing protocols incorporated the enhancements for improving the performance of the network. Though many routing metrics are available in the mesh network for finding the path from the source to the destination, some of them are studied. Fig. 2 shows the proposed routing metrics in wireless mesh network by considering the link quality, load and energy.

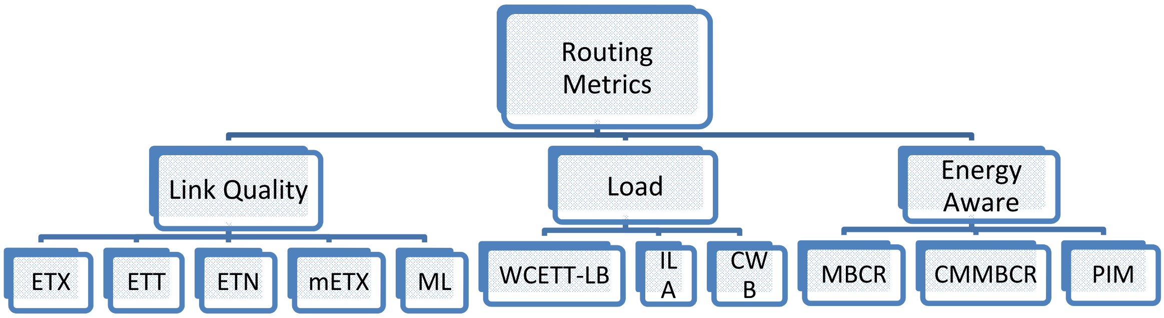

Fig. 2. Classification of Proposed Routing Metrics in WMN

IV. Previous Literature

A. *Link Quality Aware Metrics*

The metrics ETX, ETT, ETN, mETX and ML are the link quality based routing metrics. De Couto et al[16][17] proposed a first metric for WMNs is the Expected Transmission Count (ETX). This ETX is the expected number of transmissions required to successfully transmit a packet from a node to its neighbor. The metric predicts the number of retransmissions required using per-link measurements of packet loss ratios in both forward and backward directions of each wireless link. To compute ETX, each node periodically broadcasts probes which contain the number of received probes from each neighbor. The number of received probes is calculated at the last *T* time interval in a sliding-window fashion. A node X computes the ETX of the link to a node Y by using the delivery ratio of probes sent on the forward (df) and reverse (dr) directions. The df is the fraction of successfully received probes from X declared by Y and dr is the fraction of successfully received probes from Y declared by X, at the equal *T* interval. The ETX of link XY is $1/(df *dr)$. The selected route will be the one with the lowest sum of ETX along the route to the destination.

The implementation of ETX exposed two limitations; broadcasts usually are carried out at the network basic rate but probes are smaller than typical data packets. Thus, the performance of the ETX is low if the network is operating at high rates. Since it neither distinguishes links with different bandwidths nor considers data-packet sizes. To handle these issues, Richard Draves et al[18] proposed an Expected Transmission Time (ETT) which is the time required by a data packet to transmit successfully to each neighbor. The ETT adjust ETX to different PHY rates and data packet sizes. ETT is the product of ETX and the average time required to deliver a single data packet ie, $ETT= ETX * t$. The value of t is estimated by dividing a fixed data packet size (S) by the estimated bandwidth (B) of each link; $t = S/B$. Thus ETT = ETX * (S/B). The packet-pair technique is used to calculate B of each link. This technique involves with the periodic transmission of two probe packets back-to-back, one is small and one is large from each node to estimate the bottleneck bandwidth of each link. Each neighbor node measures the inter-probe arrival period between the two packets and reports it back to the sender. The computed bandwidth is the size of the large packet of the sequence divided by the minimum delay received for that link. Richard Draves et al[18] proposed a Weighted Cumulative ETT (WCETT). This metric is the sum of the ETT of all hops on the path. The total sum of ETT is an estimate of the end-to-end delay experienced by a packet traveling along that path. It also reduces the intra flow interference by reducing the number of nodes on the path which is on the same channel. WCETT has two limitations[19], first, it does not explicitly consider the effects of inter-flow interference, even if it captures the intra-flow interference. Hence, it selects the routes in dense area and sometimes it leads to starvation due to congestion. Second, it has no efficient algorithm to calculate the minimum weight path based on WCETT since it is not isotonic. This is happened due to the lack of consideration of inter-flow interference.

The fast link quality variation is the difficulty arises in the wireless network. Metrics based on average values such as ETX may not follow the link-quality variations and it produces excessive control overhead. Furthermore, each node should be aware of the total number of nodes in the network; in large networks this process becomes expensive. To cope this issue C. E. Koksal et al[20] proposed the two metrics modified ETX(mETX) and Effective Number of Transmissions(ENT). Both metrics are designed based on the basis of link variance so as to make the ETX as a quality aware metric. The mETX is calculated by broadcasting probes. The mETX calculates the error probability by the dependence of these bit errors in the subsequent transmissions. ENT is an alternative method to measures the number of successive retransmissions per link by considering the variance. ENT performs the route computation by considering the acceptable number of retransmissions per link. If a link has a number of expected transmissions which are higher than the maximum then ENT omits this link from the routing computation.

Passos et al[21] proposed the minimum loss (ML) metric based on probing to compute the delivery ratio. In ML metric, the route is chosen based on the lowest end-end probability. In addition to that, ML is a multiplicative metric and it is calculated by multiplying the delivery ratios of the links in the reverse and forward directions to find the best path. The ML has advantages over ETX since ETX is only an additive metric. Due to the multiplication process, it reduces the frequent route changes and thus improves the performance of the network.

B. Load Aware Routing Metrics

Liang Ma et al[22] proposed a routing metric known as Weighted Cumulative Expected Transmission Time with Load Balancing (WCETT-LB) for wireless mesh networks. WCETT-LB is an enhancement over WCETT metric by incorporating load balancing scheme. WCETT-LB implements load balancing at mesh routers. WCETT-LB provided a congestion aware routing and traffic splitting mechanism by dividing the traffic among the mesh routers. It also handled the inter-flow and intra-flow interference in the network. The proposed metric is based on the following architecture. The architecture consists of three layers such as upper, middle and lower. The upper layer is wired Internet, the lower layers connected through the gateways. The middle layer has mesh routers and which is connected to both the gateway and the mesh clients in the lower layer. The mesh routers form a mesh backbone for providing Internet services. The mesh clients in the lower layer request Internet services through mesh routers. Mesh clients can be connected to a backbone in a single hop or multi hop fashion. The load balancing component consists of two parts: congestion level and traffic concentration level at each node in a particular path. The congestion level of each node is determined by considering the average queue length of each node in a particular path. If the average queue length is greater than a threshold, then the path is heavily loaded. This metric used threshold value for checking the congestion level and it reduces communication overhead.

Manikantan Shila, D., et al[23] proposed a new routing metric called as Interference-Load Aware(ILA) metric which was incorporated in the well known AODV routing protocol. The ILA metric is composed of two components: Metric of Traffic Interference (MTI) and Channel Switching Cost (CSC). The two components of ILA capture the effects of intra-flow and inter-flow interference, difference in transmission rates, packet loss ratio and congested areas. To capture all the characteristics of a mesh network, the ILA metric combines MTI and CSC to form a new path weight. The MTI captures the intra-flow interference while CSC captures the intra-flow interference. The MTI considers the traffic load of interfering neighbors. Due to the shared nature of wireless medium, it results in both an inter-flow and intra-flow interference. The degree of interference depends on the amount of load generated by the interfering node and not on the number of interfering nodes. Using CSC, the two paths have same MTI weight, chooses the different channels to transmit data to reduce intra-flow interference. The aim of the proposed metric is to find paths with less congestion, minimum packet loss, low level of interference and high data rate. Towards the end, the mesh routers are required to keep track of the traffic load on themselves, as well as their neighbors. The traffic load of the neighbors is a potential source of interference and paths with high interference should be avoided.

TABLE 1
Summary of Link Quality, Load and Energy Aware Routing Metrics

Category	Metrics	Authors	Objectives	Path Selection Criterion	Limitations
Link Quality	ETX	De Couto et al[16]	Predicts the number of retransmissions required using per-link measurements of packet loss ratios in both directions of the link.	Forward and backward delivery ratios of the link	It does not differentiate between bandwidths nor considers data-packet sizes.
	ETT	Richard Draves et al[18]	ETT is the combination of packet loss rate and transmission rate of each individual link and it measures the different transmission rate of different communication links.	Forward and backward delivery ratios of the link and throughput	Unaware of traffic load, interference and channel diversity
	ENT mETX	C. E. Koksal et al[20]	Measures the number of successive retransmissions per link by considering the variance.	losses by means of bit error probability	Fails to capture link quality in terms of inter flow and intra flow interference.
	WCETT	Richard Draves et al[18]	Reduces the intra flow interference by minimizing the number of nodes on the path which is on the same channel.	end-end delay and channel diversity	Fails to capture inter flow interference and traffic loads.
	ML	Passos et al[21]	The route is chosen based on the lowest end-end probability and it reduces the frequent route changes in the network.	packet delivery ratio and end-end loss probability	It does not differentiate between bandwidths nor considers data-packet sizes.
Load Aware	WCETT-LB	Liang Ma et al[22]	Provides the distribution of load in the network to avoid congestion and reduces the intra flow interference.	end-end delay and channel diversity and queue length	It does not perform well in multi-radio networks.
	ILA	Manikantan Shila, D., et al[23]	Finds path with less congestion, minimum packet loss, low level interference and high data rates.	Inter and Intra-flow interference and traffic load	It may not be suitable for congested areas.
	CWB	Nguyen, L. T., et al [24]	Balances the traffic and improve network capacity by avoiding routing traffic through congested areas.	Individual link weights	It fails to capture the intra flow interference.
Energy Aware	CMMBCR	C.K. Toh et al[27]	Finds the node with remaining battery capacity which is above threshold to avoid node failure problem.	Remaining Battery Capacity greater than threshold	There is no guarantee that it minimizes the total energy consumed.
	MBCR	J.P.Sheu et al[25]	Balancing energy consumption of the entire network by considering the remaining battery capacity.	Remaining Battery Capacity	Selects the route with nodes having the low remaining battery capacity and it leads to node failure.

Nguyen, L. T., et al [24] proposed a load and interference-aware routing metric for wireless mesh networks, named as Contention Window Based (CWB) metric. This metric assigns weights to individual links based on the channel utilization and the average Contention Window used on these links. The individual link weights are combined into form a path metric that accounts for load balancing and interference between links which use the same channel. The proposed routing metric consists of two parts: the congestion level and the channel utilization on a given node. The congestion level on each link of the node determines the difficulty of successful transmission of a frame on that link. The congestion level is measured by using the average value of Contention Window (CW) on the wireless link. The channel utilization represents the fraction of channel time in which the channel is sensed busy. The higher the value of channel utilization, the less the traffic can be added to send over the channel and the longer the node has to defer before it can send its own frame. When channel is saturated, although input traffic increases, channel utilization still is constant because all time slots are utilized. Thus the CWB metric helps the routing protocol to balance traffic and improve network capacity by avoiding routing traffic through congested areas.

C. Energy Aware Routing Metrics

Minimum Battery Cost Routing (MBCR), To balance the energy consumption of the entire network, J.P.Sheu et al[25] proposed the *Minimum Battery Cost Routing* (MBCR) metric which considers the remaining battery capacity(R_{brc}) of a node. The R_{br} is defined as the ratio between the energy used(E_i) and the maximum initial battery capacity(E_{max}). Initially, all nodes having the same battery capacity and a cost value $f_i(E_i)$ is assigned to each node based on its remaining battery capacity.

$$f_i(E_i) = \frac{1}{E_i}$$

The drawback of MBCR is, it selected the route with nodes having the low remaining battery capacity. It leads to node failure problem during the transmission. This problem can be overcome by dividing the nodes into three categories[26] based on its cost value $f_i(E_i)$. The nodes which are having the remaining battery capacity with less than 10% their initial battery capacity belongs to first category. The routes having this type of nodes are not considered by the routing algorithm if an alternative route is available to avoid route discovery latency. The second category includes the nodes which are having their remaining battery capacity between 10–20% of their initial battery capacity. The route having this second category indicates that the nodes are running out of energy thus the routing algorithm should avoid them if possible. The nodes having the remaining battery capacity which is above 20% of their initial capacity belongs to third category. The routing algorithm usually selects the route with this third category.

C.K. Toh et al[27] proposed a Conditional max-min battery capacity routing (CMMBCR) routing metric which is a combination of MTPR[28] and MMBCR[29] metrics. Firstly, this metric finds the path using MTPR with the condition of that all nodes having a remaining percentage of battery capacity which exceeds a threshold value γ. The threshold γ acts as a tuning knob to shape the behavior of the metric towards the one or the other metric. If γ=0, the CMMBCR can be reduced to the MTPR metric, whereas for γ=100, the CMMBCR metric behaves like the MMBCR metric.

V. Conclusion

Routing in WMN is an important research issue in recent world. Routing metrics play a vital role in routing protocols for selecting an efficient route from the source to the destination. Due to some limitations of default hop count metric, certain routing metrics were proposed in Wireless Mesh Network. This paper studied the proposed routing metrics in WMN. The different categories of metrics such as link quality, load and energy aware were studied. The summary of these proposed metrics in shown in Table 1. The proposed routing metrics provides better throughput and reliability to some extent by considering different optimization objectives and applying various techniques such as active probing, prediction of link quality, determining the load and residual energy monitoring. The routing protocols related with the above mentioned metrics will be studies in the future.

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