An Analysis Of Routing Protocol Metrics In Wireless Mesh Networks

Fariborz Entezami and Christos Politis
Wireless Multimedia & Networking (WMN) Research Group
Faculty of Science, Engineering and Computing (SEC)
Kingston University London, KT1 2EE London, United Kingdom

***Abstract*—Wireless Mesh Networks (WMN)s play an important role in today communication and they are expected to increase in proliferation in the field of wireless communication in the near future. Researchers in the area of WMNs address some issues like low throughput and high latency. Routing Protocols in WMNs have a vital role in data communication and the key parameter in all routing protocols is link metrics. In this paper the majority of link metrics in WMNs are studied in different categories. Link-quality and traffic-aware metrics account for most of the metrics, however multi channel network and cognitive radio systems are also considered in detail. In each section, by reviewing the metrics and its performance in detail, summary and comparison tables of link quality metrics are also provided to enable better understanding of this topic.**

***Index Terms*—Hop-Count, Link Metrics, Link-quality metrics, Multi channel metrics, Traffic-aware link metrics**

I. INTRODUCTION

Wireless mesh networks consist of wireless nodes in an area where nodes can only communicate directly with others which are within its transmission range. Nodes which need to send information to other nodes outside of its radio frequency coverage will use intermediate nodes to act as routers to receive the information and forward them to other nodes to traverse the network towards the destination [1]. The routing protocol which is used by the network plays a key role in the perceived performance and a major part of each routing protocol is the link metric [2]. The metrics that are used in wired networks cannot be extended to wireless networks for the reasons that wireless links often have more packets lost than wired network [3]. Additionally, wireless nodes use the electromagnetic spectrum as its sole medium and all neighbours can cause interference to the communication channel, thus affecting throughput performance when it is compared with wired networks [3].

Hop count is the traditional and most popular link metric in WMNs. It is simple to calculate but does not take into the account the link quality and for this reason it is not accurate enough to estimate the path cost as the cost is equal to only the total number of routers through the path [4]. To improve metrics in routing protocols, more parameters such as interface bandwidth or path delay are considered in the calculation to choose the best path and are able to estimate link quality with more accuracy. These kinds of routing metrics are categorized as link-quality metrics and examples are Expected Transmission Count (ETX) [5], Expected Transmission Time (ETT) [6], or Effective Number of Transmission (ENT) [4].

The radio communication is often unpredictable and the property of a radio channel between nodes is not stable. Background noise, obstacles, channel fading and interference are some examples which cause the channel qualities to often vary with time [4]. Authors in [7] show that the influence of the wireless channel characteristics impact performance significantly more than node mobility in a practical environment. They also found that transmission interference behaviour is highly dependent upon the wireless link loss rates [5], [8]. Interference could be *intra-path* interference, where transmissions on different links in a path interfere with one anothers or *inter-path* interference that is the result of transmission interference on links in different paths. In Load-dependant metrics [9], the best route is selected based on link quality and the estimation of traffic load on nodes which participate in the route, while link-quality metrics [9] choose routes based only on the quality of links through the route.

Interference in wireless links in unlicensed spectrum could be *controlled* or *uncontrolled* [10]. When a wireless node uses a channel, the nature of wireless broadcast produces interference to the entire neighbourhood of the node which are within signal coverage area. This interference is called *controlled interference*. *Uncontrolled interference* is the result of other equipment which operates in the same frequency band but does not utilise the protocols which are used in the wireless network. *Uncontrolled interference* could result from a range of devices that operate in same frequency such as Bluetooth devices or microwave ovens which work in 2.4 GHz [10], [11].

Two main differences make *traffic aware* routing metrics exhibit better performance than *link quality based* ones. Firstly, links with higher bit rates have more efficiency than the links with lower bit rates. Conversely, nodes which have congested links and where collisions are prominent have lower performance than the other nodes where the wireless medium is under-utilised. Some newly proposed metrics such as Expected Link Performance (ELP) [9], Distributed Based Expected Transmission Count DBETX) [5] and Expected Available Bandwidth (EAB) [12] have better performance in finding the best paths than the link quality metrics. They consider link quality and also monitor the network for inter and intra path interference to recognize busy links and bottlenecks in the network and avoid using them in sending packets to destinations [13], [14].

To increase wireless capacity in the network, two approaches can be selected. Firstly, increase the data rate in the wireless channel that uses a fixed amount of spectrum by improving modulation, modifying antenna and Media Access Control (MAC) protocols to increase bits/sec/Hz. The second approach involves each node using a different frequency to communicate with other nodes, thus nodes in same communication area can communicate simultaneously at the same time by utilising different frequencies [10]. For increasing the network capacity and reducing interference, multi radio interfaces have been utilized in WMNs by assigning different channels to network access points to support multi transmitting simultaneously in the neighbouring region. In addition, it takes advantage of channel diversity for load interference balancing within the access points. Real time monitoring can also be used as a performance enabler to achieve lower end-to-end delay [15]. Metric of Interference and Channel-switching (MIC) [6], Weighted Cumulative ETT (WCETT) [16] and Weighted Hop, spectrum-Awareness and sTability (WHAT) [17] are some metrics that support multi radio channels in WMNs [18].

The remainder of the paper is organized as follows, link metrics are considered in four different categories, traditional metric is considered in section II, and then link quality metrics are considered in the section III. In section IV, the Load-dependant metrics are described and section V considers the multi channel metrics. Section VI is system models and simulation evaluations. The last sections present the future works and conclusion.

II. TRADITIONAL ROUTING METRIC

Hop count is the most popular and The Internet Engineering Task Force (IETF) standard metric. It is simple to compute by devices which have low resources in Central Processing Unit (CPU), memory or energy such as Wireless Sensors. This metric avoids any computational burden on devices regarding calculating the best route to the destination. The path weight is equal to the total number of routers through it. The most traditional routing protocols such as Ad hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR) use hop count to select the best path which does not show the best performance in Ad hoc WMN [19]. This metric does not take into account packet loss ratio, transmission rate or interference when calculating the link cost [2], [16]. Hop count is more attractive where computing link quality is very costly such as in networks with high mobility [2], [20], [21]. The hop count routing metric inherently quantizes the state of a communication link between two nodes as up or down state and other parameters of the links quality does not come into the account [4].

III. LINK-QUALITY METRICS

Link-quality metrics evaluate the quality of each link in the path and also the cost of each link which is based on parameters such as bandwidth, packet latency and packet loss. Hop count as a traditional metric does not consider the wireless link quality. Thus, when using the hop count metric, a link with high capacity of bandwidth, low packet latency and less interference has equal cost to a link with low bandwidth, high packet latency and high interference levels. The hop count metric forces the routing protocol to choose the path with fewer hops without considering the link-quality of each path, this will result in avoiding using a path with a higher number of hops, even though a path may be available with higher hop count but improved total performance along the path.

A. *Expected Transmission Count (ETX)*

ETX [5] is calculated based on packet loss rate that is collected from the MAC layer and is the predicted value of data transmissions that deliver a packet successfully over a wireless link. ETX is a metric that is calculated by each node for each link. The calculation is based on the probability that packets are successfully transmitted between sender and receiver in a bidirectional manner. Forward delivery ratio or d_f is the probability that a packet is received successfully at the receiver end. The probability that a packet is received successfully at the sender end is called reverse delivery ratio or d_r. Reverse delivery ratio is calculated based on reception of Acknowledgement ACK packets that the receiver sends to the sender in order to acknowledge that a packet was successfully received. The probability that a packet is sent to the receiver and a receiver acknowledgment is received by the sender is d_f *d_r. ETX is defined as the expected number of transmission for a successful transmission of a packet in 1 hop as shown in equation (3) [5].

$$p = 1 - (d_f \times d_r) \quad (1)$$

$$ETX = \sum_{K=1}^{\infty} kp^k (1 - p)^{k-1} \quad (2)$$

$$ETX = \frac{1}{1-p} = \frac{1}{d_f \times d_r} \quad (3)$$

ETX sends a small packet with the size of 134 bytes every second and calculates the delivery ratio based on a large window that is typically 10 seconds in order to dampen the variation in the delivery ratio due to interference [9], [22]. ETX is the second well know and common metrics that is used in many routing protocols. Its calculation is not heavy and it can even be used in low energy devices like wireless sensor networks. Although, ETX creates more overhead than Hop-count, however, the increase in overhead can be negligible when the associated increase in throughput is considered [2].

ETX calculation is based on small packets and it is possible to degrade the link performance based on the case if the packets are significantly large and it is one of the weaknesses of ETX [9]. The main limitation in ETX is not taking into account the asymmetry of traffic on a wireless link. ETX is designed for a single radio with a single channel environment. Also the link interference is not taken into account when computing the calculation of this metric.

ETX is suitable for short routes with fewer hops and is not suitable for longer paths because longer paths have multiple links that can transmit concurrently. In case of reusing the channel, the actual path cost will be lower than the sum of the transmission counts of all links in the path [3]. For this reason ETX does not work properly in longer path and this makes ETX more conservative estimate for path cost for paths which have more than 3-4 hops [3].

Authors in [8] show that the paths with same sum of ETXs could achieve very different data output rate as it does not take into the account transmission rate in different links [16]. It also does not consider the mechanism on MAC backoff, and it is not a multi radio channel support metric [8]. ETX also does not have any mechanism to encounter interference that could become bottleneck in the network [16].

B. *Potential Transmission Count (PTC)*

Potential Transmission Count (PTC) has been introduced as a metric that is based on the total number of packets transmission and retransmission required in a link to send a packet successfully. PTC is calculated as the inverse of the probability of successful transmission as shown in equation (4). It is based on link-layer ACKs in

Institute of Electrical and Electronics Engineers (IEEE) 802.11 [7].

$$PTC = \frac{1}{d_f * d_r} \quad (4)$$

Equation (4) shows the calculation of PTC [7]. It has exactly the same patent as ETX does and it was not a novel metrics as ETX has been published before.

C. Average Expected Transmission count (AETX)

Authors in [23] have shown that ETX fluctuation with time affects routing protocols performance and have proposed the moving Average Expected Transmission count (AETX) metric. AETX which is based on the last three average of ETX makes this metric more stable with better performance in the case of topological variations over the channel in the period of channel monitoring. Equation (5) shows calculation of AETX[23], [24], [25].

$$AETX = (\sum_{i=n,-1}^{n-3} ETX(i))/3 \quad (5)$$

D. ETX for multimedia (ETXMulti)

Multimedia traffic accounted for more than 50% of all communication traffic in 2012 and there is a prediction that it will increase to 80% in 2022 [26]. ETX for multimedia (ETXMulti)s authors in [26] have presented a new routing metric based on ETX concept to ensure that it finds the best path for multimedia traffics. Real-time multimedia applications do not use Transmission Control Protocol (TCP) for their communication and instead they use User Datagram Protocol (UDP) which does not use ACK in its mechanism. ETX is based on the probability of success transmission in both ways and instead UDP protocol only uses one way communication and ACK is not sent back to sender in UDP mechanism. ETXMulti has been designed for UDP protocol and takes into the account the probability for forwarding packets.

$$ETXMulti = \frac{1}{d_f} \quad (6)$$

Equation (6) shows ETXMulti calculation where *df* denotes the probability that a packet successfully reaches the next neighbour node [26]. ETXMulti is similar to ETX and it has all its Pros and Cons.

E. ETX-Embedded

ETX-Embedded [27] has been proposed based on the combination of the network topological structure and channel quality. The geographic routing is an ideal approach for routing protocols to find the best path in an end to end manner. In geographic routing, it is assumed that a packet can be moved closer to the destination in the network topology if it is moved geographically closer to its destination in physical space [27]. This assumption is correct wherein the wireless network nodes are distributed uniformly and use the wireless channels with perfect transmission status. Sometimes, the geographical routing may lead a packet to a local minimum or low quality route [27]. ETX-Embedded accurately considers the networks topology as well as channel quality and make it feasible to run on small nodes such as wireless sensors [27]. ETX-Embedded improves the end-to-end routing performance by embedding a wireless network into an Euclidean space, where the virtual distance of each node equal to the ETX or probability that packets are successfully transmitted between sender and receiver [27].

$$\delta(X_i, X_j) = min_{l_i \in L} ETX(l_i) \quad (7)$$

Equation (7) shows the ETX-Embedded where L is the set of routing paths between nodes X_i, X_j and l_i is the link between nodes X_i and X_j [27]. In greedily forwarding algorithm, the packet is forwarded to the next hop from the neighbour nodes which the ETX node summary to the destination is minimized. Assuming we need to send packets from node X_j to X_k and node X_i is an intermediate node from a set of N neighbour nodes, then the intermediate node is chosen by equation (8) [27].

$$X_j = arg\, min_{X_j \in N}(\delta(X_i, X_j) + \delta(X_j, X_k)) \quad (8)$$

For embedding a wireless network into a low-dimensional Euclidean space with MultiDimentional Scaling (MDS) [28], there is a need to have the measurement of ETX distances between all pairwise nodes in the network. Instead of measuring ETX as a distance between each pair, a set of beacon messages broadcast by a set of reference points is used. Each beacon message is sent with a transmission counter initialized by zero. This transmission counter increases by each transmission or retransmission. Each node finds the smallest transmission count through all received beacon messages and the node can forward its ETX distance to the sampling beacon. In this method, all the beacons are embedded based on measurements between any beacons pair into the low dimensional space and other nodes can be added according to their relative ETX-distance to the beacons. The accuracy in embedding depends on sufficient number of beacons which are uniformly distributed such that sampling beacons are fully representative of networks spatial characteristics [27]. ETX-Embedded is an optimal end-to-end routing metrics that causes small overhead and makes it a suitable metric for resource-constrained devices in complicated environment.

F. *Statistical Estimate Routing Metric (SERM)*

Statistical Estimate Routing Metric (SERM) [29] has been published as an ETX based metric with the aims of working on limited energy devices with reliable transmission such as wireless sensor network. SERM is based on statistics mean of packet reception ratio and also correlation coefficient of moment estimator [29]. Authors in [29] show $\hat{\rho}(P_{ij}, P_{ji})$ as moment estimator of correlation coefficient for link between nodes i and j, and they show that smaller values of $\hat{\rho}(P_{ij}, P_{ji})$ indicates poor stability of link P_{ij}, P_{ji} and this link is considered not to be used. The equation (9) shows the calculation formula of moment estimator of correlation coefficient [29].

$$\hat{\rho}(P_{ij}, P_{ji}) = \frac{S_{ij}}{(S_i \times S_j)} \quad (9)$$

S_i^2 and S_j^2 are variance of packet reception ratio for node *i* and *j* respectively and S_{ij} is variance covariance for the two nodes.

$$S_i^2 = \frac{1}{n}\sum_{K=1}^{n}(P_{Kij} - \overline{P_{ij}}) \quad (10)$$

$$S_j^2 = \frac{1}{n}\sum_{K=1}^{n}(P_{Kji} - \overline{P_{ji}}) \quad (11)$$

$$S_{ij} = \frac{1}{n}\sum_{K=1}^{n}(P_{Kij} - \overline{P_{ij}})(P_{Kji} - \overline{P_{ji}}) \quad (12)$$

Equations (10), (11) and (12) shows hoe to calculate SERM where $\overline{P_{ij}}$, $\overline{P_{ji}}$ are statistic mean of packet reception ratio for node *i* and *j* after *n* cycles and S_i^2, S_j^2 are variances of packet reception ratio for two nodes. S_{ij} is variance covariance for the two nodes [29]. SERM is a suitable metrics for the environment with instability and also non-symmetry in the links. It has been shown that in such mentioned environments, SERM performs better than hop-count and ETX [29]. SERM does not need heavy calculation and it is applicable on energy limited devices.

G. *Expected Forwarding Counter (EFW)*

Nodes in WMNs have a tendency to be selfish in order to increase their network utilization by prioritizing their own traffic and dropping selected packets from neighbouring nodes/routers. To cope with this problem, authors in [30] proposed a novel routing metric called EFW. It is a metric with combination of ETX and forwarding behaviour. To address the selfish behaviour of nodes, the proposed Expected Forwarding Counter (EFW) metric considers the forwarding reliability of relaying nodes in its path calculation. $P_{d,ij}$ denotes the dropping probability of node *j* and the forwarding probability is calculated (1- $P_{d,ij}$).

$$EFW = \frac{1}{P_{fwd,ij}} = \frac{1}{(1-P_{ij})\times(1-P_{ji})} \times \frac{1}{P_{d,ij}} \quad (13)$$

Equation (13) shows how to calculate EFW where P_{ij}, P_{ji} are packet reception ratios for node *i* and *j* in both directions [30]. To calculate EFW, the network topology in a directed graph mode should be kept in memory. However, this will result in increased resource consumption and more computational analysis in wireless nodes. It is possible that the forwarding probabilities of two wireless nodes may differ. (i.e. for nodes i , j $P_{fwd,ij} \neq P_{fwd,ji}$, therefore, selecting path for forward and reverse transmission may differ and these affect network performance [30]. To cover these points, two further refinements; Maximum Expected Forwarding Counter (MEFW) and Joint Expected Forwarding Counter (JEFW) have been introduced in equations (14) and (15) that avoid using a link by considering the worst and the joint dropping behaviour [30].

$$MEFW_{ij} = \frac{1}{(1-P_{ij})\times(1-P_{ji})} \times \frac{1}{(1-Max(P_{d,ij}, P_{d,ji}))} \quad (14)$$

$$JEFW_{ij} = \frac{1}{(1-P_{ij})\times(1-P_{ji})} \times \frac{1}{(1-P_{d,ij})\times(1-P_{d,ji})} \quad (15)$$

Where P_{ij}, P_{ji} are packet reception ratios for node *i* and *j* in both directions and $P_{d,ij}$ is dropping probability of node *j* and the forwarding probability is calculated (1- $P_{d,ij}$). MEFW takes into account the maximum dropping probabilities and JEFW considers the cumulative effect of selfish behaviour by multiplying the forwarding probabilities of two nodes [30]. EFW with two alternative refinements (MEFW, JEFW) as a cross-layer routing metric has been examined and the results show that it is a suitable routing metric to selects the most reliable path based on quality of wireless link and it also considers the forwarding behaviour to increase network throughput and also fairness.

H. Modified ETX (mETX)

The most popular ETX based metric is modified ETX (mETX) [4]. It considers significant changes in communication channels during a time period. It considers how time-varying channels affect throughput, and by considering a variety parameters in communication channel and taking them into the optimized routing metrics, it could improve communication performance in wireless networks [4]. mETX is based on two parameters, average error probability and the variance of the error probability [4]. $\frac{1}{P_{c,k}}$ is called the instantaneous number of transmissions that signifies the number of transmissions for successful reception based on probability of an error-free packet $P_{c,k}$.

It is assumed that $P_{B,t}$ is probability of bits transmitted at time t which are not detected by the intended receiver. t_k is the starting time for transmission of the k^{th} packet and $\eta_{B,t}$ defines as $-log(1-P_{B,t})$ and S is period of observation:

$$P_{B,t} \leq \eta_{B,t} \leq P_{B,t} + \frac{{P_{B,t}}^2}{1-(P_{B,t})^2} \qquad (16)$$

$$P_{B,t} \cong \eta_{B,t} \qquad (17)$$

$$\frac{1}{P_{c,k}} = exp(\sum_{t=t_k}^{t_k+S-1} \eta_{B,t}) \qquad (18)$$

$$\sum_k = \sum_{t=t_k}^{t_k+S-1} \eta_{B,t} \qquad (19)$$

Equations (16)-(19) show the calculation of $\mu \sum$, σ_{Σ}^2 which are mean and variance of $\sum_k$ respectively and they are error probabilities [4].

$$mETX = exp(\mu \sum + \frac{1}{2}\sigma_{\Sigma}^2 \ ) \qquad (20)$$

Equation (20) shows how to calculate mETX and it is obvious that it is increased by increasing $\mu \sum$ which is the average level of the bit error rate probability over a period of time. The variant of the packet delivery is monitored by σ_{Σ}^2 [4].

mETX does not take intra-flow interference into consideration and it is an optimized metric for energy conservative networks such as wireless sensor. [4] showed that by using mETX, the average packet loss rate achieved up to 50% better performance than ETX [4].

I. Effective Number of Transmission (ENT)

ENT [4] is based on calculation of packet loss such as ETX and mETX and it considers the visibility of packet loss for upper layers protocols such as TCP and also the maximum transmission limits in higher layers. ENT takes M as the maximum limitation of retransmission for upper layer in the metric calculation. ENT is an advanced version of mETX, and based on mETX calculation and equations 16-19, the ENT calculation can be given in equation (21) [4].

$$P\left(\frac{1}{P_{c,k}} \geq M\right) = p(\sum_{t=t_k}^{t_k+S-1} \eta_{B,t} \geq LogM) \cong exp(-\frac{1}{2}(\frac{LogM-\mu_{\Sigma}}{\sigma_{\Sigma}})^2) \qquad (21)$$

Where $P_{c,k}$ is probability of an error-free packet t_k is the starting time for transmission of the k^{th} packet and $\eta_{B,t}$ defines as $-log(1-P_{B,t})$. S is period of observation and $\mu \sum$, σ_{Σ}^2 are mean and variance of $\sum_k$ respectively and they are error probabilities. ENT assigns cost of ∞ to the links that have $log(ENT)>log(M)$. ENT is aware of probe size and considers the standard deviation to observe data transmission variation along with average of the link quality but it does not take into the account intra-flow interference [4].

J. Expected Transmission Time (ETT)

The motivation of ETT [6] was to improve ETX by bringing the parameters of transmission rate and packet size into the path calculation. The cost of a link is calculated based on MAC layer duration for a successful transmission.

$$ETT = ETX \times \frac{S}{B} \qquad (22)$$

Equation (22) shows calculation of ETT where S is the packet size, B is transmission rate of the link and ETX as it has been described early. The cost of the path is calculated by the summation of the ETTs of the links on the path [6]. ETT just like ETX is isotonic, another drawback in ETT is that it does not calculate the inter-flow and intra-flow interferences and it does not have any mechanism to encounter interference that could become bottleneck in the network [16][6].

ETT is suitable for short routes with fewer hops in the network, it is not suitable for longer paths as longer paths could have multiple links that can transmit concurrently because they are not in same contention domain. Actually in case of reusing the spatial, the actual path cost is lower than the sum of the transmission counts of all links in the path [6].

K. Medium Time Metric (MTM)

The traditional routing metric such as hop count is used in single rate networks but Medium Time Metric (MTM) [31] has been designed for use in multiple transmission rates networks. MTM can be calculated on below:

$$MTM(_{ij}, p) = \sum_{\forall e \in \pi_{ij}} \tau(e, p) \quad (23)$$

Equation (23) shows the calculation of MTM where $\tau(e,p)$ is the time required to transit a packet *p* over edge e. $\tau(e,p)$ takes into account the overhead that include contention, headers and multiple frame exchanges. π_{ij} is path for packet p. MTM finds paths with the minimum total transmission time and it simultaneously optimizes the usage of the medium by maximizing end-to-end path capacity [31]. MTM increases path capacity by minimizing medium time consumption. Maximizing residual capacity available to other flows minimizes medium time consumption. MTM avoids to prone to oscillating by tracking path capacity. Path capacity is opposed the path utilization and using it increases path elasticity in case of mobility [31].

$$\tau(e,p) = \frac{overhead(e) + \frac{size(p)}{rate(e)}}{reliability(e)} \quad (24)$$

Equation (24) shows calculation of $\tau(e,p)$ where *overhead*(e) is the average of overhead per packet including control frames, contention backoff and fixed headers. *reliability*(e) is the fraction of successfully received packets. *rate*(e) is the selected transmission rate and *size*(p) is the size of the data payload [31]. In multi-rate networks, long distance link can experience low effective throughput and low reliability as a result of low/weak signal level. MTM has the capability to avoid the use of long distance link, hence it could experience relatively higher throughput and more reliability [31].

L. Expected Multicast Transmission Time (EMTT)

Expected Multicast Transmission Time (EMTT) has been published as a high throughput and reliable multicast metric in multi-rate wireless mesh network. EMTT takes into account the reliability in MAC layer retransmission, transmission rate diversity, link quality awareness and wireless broadcast services [32]. The end to end Packet Delivery Ratio (PDR) is considered in the EMTT calculation for every transmission rate from the sender to the receiver in the next hop. EMTT uses Markov Decision Process (MDP) theory as a model to rate adaptation process, calculate EMTT metric and to determine the optimal rate adaptation policy [32].

Rate adaptation is the first phase of calculating EMTT. In this phase, link-layer acknowledgement mechanism enables the sender to reduce its transmission rate when none of the next hop nodes have received the multicast packets. This is achieved by applying an adaptation scheme based on transmission rate information received [32]. $\Pi_{i,s}$ denotes the best transmission rate for node *i* in state of *S* that is subset of next hop receivers R_i of node *i*. This phase defines a policy to guide the sender to choose the best transmission rate when the process is in a particular state and then in next phase the optimal policy of rate adaptation in different state can be determined in EMTT calculation.

EMTT uses MDP for modelling the sequential decision in rate adaptation process. For each forwarding node in multicast session, it is modelled as a stationary infinite-horizon MDP [32]. The list of actions that each nodes could choose from when making decisions on each MDP states forms a policy. The goal of the MDP is to find the optimum policy to meet the other specifications in the model. The specification of MDP could be termed as a revenue, then MDP optimization criterion would be maximizing the expected total revenue or if it termed as a cost, then it would be minimizing the expected total cost [32].

The EMTT of node *i* at state *S*, which is the state when none of the nodes has received multicast packets can be calculated as:

$$EMTT_{i,s} = Min_k(C_{k,s} + \sum_{S' \in S} P_{S,K,S'} EMTT_{i,s}) \quad (25)$$

$$C_{K,S} = \frac{L}{r_k} \quad (26)$$

$$P_{S,K,S'} = \prod_{u \in S-S'} P_{i,k,u} \prod_{v \in S'} (1 - P_{i,k,u}) \quad (27)$$

Equations (25)-(27) show how to calculate EMTT where L denotes the multicast packet size and r_k denotes the transmission rate in k^{th} transmission, $P_{S,k,S'}$ denotes the probability of k^{th} transmission. EMTT as a multi-rate support metric considers MAC-layer retransmission-based reliability and also link quality that can effectively reduce the end-to-end latency by increasing packet delivery ratio [32].

M. Estimated Transmission Time (EstdTT)

[22] used Estimated Transmission Time (EstdTT) for the SrcRR [22] which was a new routing protocol for 802.11 mesh networks. They used an extended version of ETX by predicting the best 802.11 transmission bit rate. The goal of EstdTT was to predict the time that each packet will use the channel and make it busy. The sum of the EstdTT of each link represents the total cost of the route. SrcRR as a routing protocol sends a set of broadcast probes in each node based on all 802.11 bit rates and then predicts the best possible throughput in each link to nodes neighbours. EstdTT is calculated based on the highest possible throughput and the delivery probability of ACKs in both directions [22].

$$EstTT = \frac{1}{P(ack) \times r_t} \quad (28)$$

$$r_t = max(r_1, r_2, r_{5.5}, r_{11}) \quad (29)$$

Equations (28) and (29) show the calculation of EstdTT where $P(ack)$ is the probability of delivery of ACKs on probe losses in both direction and r_t is the estimated throughput at bit rate of megabit per second. SrcRR sends an average of five probe packets in every 10 seconds in 802.11b standard. One small probe packet at the communication rate of 1 Mbps and one 1500 bytes packet at each 802.11b bit rates (1,2,5.5,11 Mbps) are sent. Each probe packets are sent at independent random intervals in 10 seconds period [22]. EstdTT is very similar to ETT and the only difference is that it does not take into account the packet size. The Pros and Cons are similar to ETT.

N. Weighted Integrated Metrics (WIM)

Weighted Integrated Metrics (WIM) [33] has been proposed as a dynamic and generic routing metrics which could be used in a wide range of routing protocols for finding reliable paths with consistent throughput. Authors in [33] claim that this metric performs well in highly unstable wireless networks [33]. WIM employs 4 different metrics and monitors the situation of these metrics in the network. The best values of each 4 metrics are calculated in equation (29) and then the margins of each metrics are calculated by equation (30).

$$BEST - Value_{ETX|RTT|HC|LT} = \frac{\sum_1^N (ETX|RTT|HC|LT)_i}{N} \quad (30)$$

$$MARGIN_{ETX|RTT|HC|LT} = \frac{(BEST - Value_{ETX|RTT|HC|LT}) - (ETX|RTT|HC|LT)}{BEST - Value_{ETX|RTT|HC|LT}} \quad (31)$$

$$BUILD = MARGIN_{ETX} + MARGIN_{RTT} + MARGIN_{HC} + MARGIN_{LT} \quad (32)$$

Equations (30)-(32) show how to calculate *BUILD* where *N* is the number of entries in the routing table, *BEST-Value* is calculated for each 4 metrics (ETX, Round Trip Time (RTT), Hop Count (HC) and Life Time (LT)) separately and then replaced the *BEST-value* to the routing table. For instance, to calculate the *MARGIN* for RTT, the *BEST-Value* for RTT is calculated based on RTT values in the routing table. *BUILD* value shows the best route by calculating *BEST-Value* and *MARGIN* of a particular metric. The *MARGIN* shows how better or worse the metric of a selected route is with regards to the *BEST* value in the routing table [33]. In another word, WIM uses four metrics and gives each metric the same weight. *BEST-value* is the average of each metric and *MARGIN* of each metric is the normalized one that makes them four absolute numbers without having any unit then they could be added in *BUILD*. By comparing *BUILD* in routing table with the new reported one from the discovery route, routing protocol decide to use the new route or use the previous one that was stored in routing table.

O. Summary of Link-Quality Metrics

Table 1 shows the comparison of different link quality metrics. The different parameters considered in this table are described below: (*i*) *Calculation Complexity* is the amount of calculation needs for running each metrics. It is from 1 (simple) to 5 (complex) and it is estimated for each metric. (*ii*) *Probability of packet loss* shows that the metric observes the communication link quality based on successful communication rate in each link. (*iii*) *Link interface specification* shows which metrics take the characteristic of network interface into account. (*iv*) *Bandwidth aware* shows the metrics which consider the bandwidth of communication channels. (*v*) *Probe size* shows the metrics that take into account the probe size. (*vi*) *Mac-Layer retransmission value* shows the metric that uses the number of retransmission of packets in MAC layer in calculations. (*vii*) *Multi-Rate support* shows the metrics that support network with multi-rate transmission over the channels. (*viii*) *Longer Path Support* shows the metrics that have better performance in running in networks with longer paths. (*ix*) *Using MAC-layer information* shows the metrics that use MAC layer data as a cross layer metrics for collecting information to calculate the metric. (*x*) *Selfishment Recognition Facility* shows the metrics that could consider the nodes that drop others packets and try to increase priority of its own packets to deliver in network. (*xi*) *Packet loss statistic analysis* shows the metrics that use statistical parameters such as average or variance of packet loss in each node to select the best path to the destination. (*xii*) *Transmission Delay Aware* considers the metrics that calculate the packet travel time and delay in packet delivery to find the best path. (*xiii*) *Asymmetry in links* shows the metrics that consider link quality of both side of a link, sending and receiving links separately.

Table 1. Link-quality metrics comparison

Link-Quality Aware Metrics Comparison Table														
Metrics Characteristics	ETX	PTC	AETX	ETXMulti	ETX-Embeded	SERM	EFW	mETX	ENT	ETT	MTM	EMTT	EstdTT	WIM
Calculation Complexity (Simple)1,2,3,4,5(Complex)	2	2	2	2	3	4	3	4	4	3	3	5	3	4
Packet loss probability	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Link Interface specification										√	√	√	√	√
Bandwidth Aware										√	√	√	√	
Probe Size									√	√	√	√	√	
Mac-Layer Retransmission Value	√	√	√	√	√	√	√	√	√	√		√	√	√
Multi-Rate Links Support										√	√	√	√	
Longer Path Support					√						√			
Using Mac-layer Information	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Selfishment Recognition Facility							√							
Using packet Loss Statistic Analysis					√	√		√	√					
Transmission Delay Aware										√	√			√
Asymmetry in Link														√

In summary, ETX is the most popular metric after HC that is simplest routing protocol metric and is used when the details of link quality are not available or it changes too much such as scenarios with nodes mobility. ETX is used in most routing protocols. ETX shows instability in real environment that AETX is the stable version of ETX. ETXMulti is ETX version for multimedia or in another word it designed for UDP packets. ETX-Embedded is more accurate version of ETX and suits for devices with limited resources such as wireless sensors. SERM is another metric that suits to limited resources devices as it does not need heavy calculation and has showed that works with better performance than HC and ETX in instability and non-symmetry environments. mETX is another metric that is optimized for Wireless Sensor Network (WSN) and observes channel changes during the time by considering the probability of packet error. EFW covers selfishness nodes issue in networks. ENT uses links with packet lost less than a maximum that has been defined in upper layer. ETT is a light weighted metric that estimates end to end delay in the whole path. EstdTT predict the best transmission bit rate and it is similar to ETT. MTM is a metric for multiple transmission rates networks. EMTT is also metric for multi rate networks with focusing on high throughput. WIM compares four metrics (ETX, RTT, HC, LT) and select the best one.

IV. TRAFFIC AWARE METRICS

More accurate cost of each link depends on the quality of the link and also other factors like the traffic on communication channels. This traffic could be regarded as the amount of data which passes through this link or other traffic which passes through other links but that interference makes neighbouring channels unusable. In this section, metrics that take into account the link quality specification and also traffic on channel are considered.

A. Distribution Based Expected Transmission count (DBETX)

DBETX [5] is a metric that its calculation is based on physical layer measurements, channel information such as level of noise and other local information such as the selected modulation scheme.

DBETX has three goals [5]; firstly, it is to monitor the variations on wireless channel, secondly, it reflects the maximum MAC layer retransmission limit and thirdly, it selects links with lower loss probability [5]. Based on these link measurements, nodes are able to estimate the Probability Density Function (PDF) of the experimented Signal-to-Noise plus Interference Ratio (SNIR). DBETX also has the ability to derive the number of required transmission. It takes the maximum number of MAC-layer retransmission into account and does not choose lossy links as it tries to find routes with lower end-to-end loss rate. DBETX is based on two parameters: Average Number of Transmissions (ANT) and the average availability per used link (defined as 1-$P_{out\,MAC}$).

$$DBETX(l) = E[ANT](l) \times \frac{1}{1-P_{out_{MAC}}(l)} \quad (33)$$

$$P_{limit} = \frac{1}{MaxRetry} \quad (34)$$

$$ANT(x) = \begin{cases} \frac{1}{P_{Suc}(x)} & P_{Suc}(x) > P_{limit} \\ \frac{1}{P_{limit}} & P_{Suc}(x) \le P_{limit} \end{cases} \quad (35)$$

Equations (33)-(35) show calculation of DBETX where P_{Suc} is the current Success Probability and P_{limit} is Limit Success Probability that is based on maximum MAC layer retransmission. *MaxRetry* is the maximum MAC layer retransmission limit [5].

DBETX can also be calculated based on expected Bit Error Rate (BER) and expected Packet Error Rate (PER) in selected modulation schemes. Received power noise and Interference Estimation are parameters which used in the calculation of Link SNIR. BER and PER on selected modulation scheme are also calculated based on Link SNIR.

$$PER(SNR) = 1 - (1 - BER(SNR))^n \quad (36)$$

Where *n* is the average packet length of the network in bit.

$$P_{Suc} = 1 - PER \quad (37)$$

$$E[ANT](l) = \sum_{SNIR=0}^{\infty} Prob(SNIR) \times ANT(SNIR) \quad (38)$$

Equations (36)-(38) show how to calculate *E*[*ANT*] where Prob(SNIR) is the probability that the link l will yield the given SNIR [5]. DBETX does not have the capability to consider longer paths due to lake of mechanism that could calculate the interferences among whole neighbours links.

B. Expected Available Bandwidth (EAB)

EAB was proposed to cover the gap of considering links with high communication traffic in previous metrics [12]. EAB claims to provide high throughput and low average end-to-end delay while the traffic is high in the network. This metrics takes into account the available bandwidth and the successful transmission ratio.

$$AB(l,t) = BW_{total}(l,t) - BW_{occupied}(l,t) \quad (39)$$

$$P_{success}(l,t) = d_f(l,t) \times d_r(l,t) \quad (40)$$

$$EAB(l,t) = AB(l,t) \times P_{success}(l,t) \quad (41)$$

Equation (39)-(41) show how to calculate *EAB* where d_f (*l*,*t*) is the forward delivery ratio and d_r (*l*,*t*) is the reverse delivery ratio based on one hop broadcast probe packet. $BW_{total}(l,t)$ is the total assigned bandwidth of an individual link and $BW_{occupied}(l,t)$ is the occupied bandwidth of link *l* [12].

EAB is very similar to ETX plus it takes into account the available bandwidth. $BW_{occupied}$ considers the bandwidth usage and BW_{total} is the total available bandwidth. EAB is more effective than ETX as the bandwidth takes a role in the cost of each link.

C. Expected Data Rate (EDR)

Authors in [8] found that transmission interference behaviour is highly dependent on the wireless link loss rates. They have proposed a transmission interference model based on the IEEE 802.11 medium access control protocol. In this model, the transmission contention degree of each link is used as wireless link loss function and also the impact function of wireless link loss on medium access backoff and concurrent transmission when two links do not interfere with each other. The aim of this metric is to develop a load insensitive metric. It does not support the dynamic interference on the link which is variable with time [8].

The Expected Data Rate (EDR) metric employs some mechanisms to be used in its calculation. Distribution Coordination Function (DCF) in IEEE 802.11 standard is used when a node wants to transmit a packet and senses the medium to check if it is free to be utilized for transmission. DCF Inter Frame Space (DIFS) is the time the medium is occupied by a node. Transmission Contention Degree (TCD) of a node is the average time that its outgoing queue is occupied and the link is going to be used. When a packet in a wireless node is transmitted, it is kept in a system memory as an outgoing queue buffer for possibility that this packet is needed to be retransmitted. It is removed from the buffer only when its acknowledgment is received. The time that the outgoing queue is occupied means the packet is waiting for acknowledgment or needs to be retransmitted because of transmission failure or packet lost. TCD defines the average time an outgoing queue of node that is not empty over a window time.

$$TCD(k+1) = Min(1, TCD(k) \times \frac{E(k+1)}{E(k)}) \qquad (42)$$

$$I(k) = \sum_{i=n_s}^{n_e} TCD(i) \qquad (43)$$

Equations (42) and (43) show how to calculate TCD where n_s, … , k, … , n_e are the links in the path which are within the interference range of link k and $E(k+1)$ and $E(k)$ are ETX value of link $k+1$ and link k respectfully [8].

$$EDR_{init}(k) = \frac{\Gamma}{E(k) \times I(k)} \qquad (44)$$

Equation (44) shows EDR calculation where $E(k)$ denotes the ETX of node k and $I(k)$ denotes the total transmission contention degree of link k. Γ is the ideal maximal data rate of a one-hop link [8]. Then, Transmission Contention Degree (RTCD) has been taken into EDR calculation by taking the influence of contention windows size on data rates.

$$RTCD(t_k) = \begin{cases} (\frac{W(k,m)}{W(k+1,m)} - 1) \times TCD(k) & (if\ P_k \geq P_{k+1}) \\ (\frac{W(k+1,m)}{W(k,m)} - 1) \times TCD(k+1) & (if\ P_k < P_{k+1}) \end{cases} \qquad (45)$$

Equation (45) shows how to calculate RTCD where P_k and P_{k+1} are loss rates of link k and $k+1$ respectfully and $W(k,m)$ and $W(k+1,m)$ are the average contention window size of nodes k and $k+1$ respectfully [8].

$$I_b = I + \sum i = t_s^{t_e} RTCD(i) \qquad (46)$$

$$EDR = \frac{r\Gamma}{E_{max} \times I_b} \qquad (47)$$

Equations (46) and (47) show the calculation of EDR where r denotes the reduction in one-hop link data rate and I_b is the total transmission interference around the highest loss rate link [8]. This new transmission interference model based metric uses an independent loss model and a temporally correlated loss model for simulating wireless link loss. EDR finds high-throughput paths in multi-hop ad hoc wireless networks. Although EDR found the best paths in the presence of temporally correlated loss, it underestimated the path throughput in some cases and it needs more improvement.

D. Transmission Failures and Load-Balanced Routing Metric (MF)

Transmission Failures and Load-Balanced Routing Metric (MF) [34] considers transmission failures by employing IEEE 802.11 backoff mechanism. A weighted mechanism is applied such that each link in the whole path has a weight. These weights are used as path metrics and can also be used as a load balancing parameters to balance traffic across the network to avoid creating congestions.

$$B(j) = max \sum_{n \in N_j} (m' - BC_{inj}) \qquad (48)$$

Equation (48) shows $B(j)$ calculation where m' is maximum backoff stages that a mesh router undergoes and BC_{inj} is i^{th} backoff stage router n on path j, where i = {0,1,2,..,7}, N_j is set of mesh routers on path j from source to destination, j=(1,2,..,P) where P is the possible multiple paths and $B(j)$ is called maximum backoff stage value among set of values on multiple paths between each source-destination pair [34].

$$C(j) = max \sum_{e \in E_j} RC_{ej} \quad (49)$$

Equation (49) shows $C(j)$ calculation where RC_{ej} is the residual capacity of link e on j^{th} path from source to destination, $e \in E_j$ and E_j is the set of links of path j [34].

$$MF = x \times B(j) + y \times C(j) \quad (50)$$

Equation (50) shows MF calculation where x,y are adjusted values that determine in the application or apply as constant values. $B(j)$ denotes the degree of reliability and $C(j)$ corresponds to the fulfilment of the user demand. The x,y act as balanced parameters between reliability and demand fulfilment. MF takes into account inter-flow interference, intra-flow interference, quality of link and have the ability to provide load balancing across the network [34].

E. *Expected Link Performance (ELP)*

ELP [9] has been introduced in order to improve the existing ETX. ELP provides an improvement over ETX by proposing a parameter such as α which gives a weight to forward packets against the backward packets.

$$P_{Success} = \alpha \times d_f (1-\alpha) d_r \quad 0.5 < \alpha < 1 \quad (51)$$

$$ELP_p = \frac{1}{\alpha d_f + (1-\alpha) d_r} \quad (52)$$

Equations (51) and (52) show the calculation of $P_{Success}$ based on α as a weighted parameter. ELP_p is calculated by equation (51) [9].

ELP is a hybrid metric that not only takes into account the link quality, but also tries to improve ETX by giving a weighted parameter to distinguish between sending and receiving packets. It also uses interface information to make it an accurate metric in estimating link performance.

Interference Factor (IF) is a parameter in ELP that estimates the medium congestion around the node. Carrier sensing in the MAC layer gives the estimation of medium congestion. The MAC layer probes the medium periodically around 100 times per second to determine whether the channel is busy or free. The ratio of the number of times that the medium is busy in comparison to the whole windows of observation gives the estimate of the medium congestion. IF is updated every second based on a moving window of the last 10 seconds.

$$IF_A = \frac{Busy_A(Rx) + Busy_A(Tx) + Busy_A(NAV)}{TotalWindowsTime} \quad (53)$$

Equation (53) shows IF_A calculation where NAV is the channel usage for other nodes communication [9].

$$IF_{AB} = Max(IF_A, IF_B) \quad (54)$$

$$ELP_{AB} = \frac{1}{\alpha d_f + (1-\alpha) d_r} \times \frac{Max(IF_A, IF_B)}{1 + Max(IF_A, IF_B)} \quad (55)$$

Equations (54), (55) show how to calculate ELP that uses three different mechanisms to accurately determine the expected link performance. In ELP, cross-layered link interference combines with link quality information to improve this metric [9]. Although link traffic and link quality play important roles in ELP calculation, bandwidth as an important resource in wireless communication is not taken into consideration.

F. *Interference and Bandwidth adjusted ETX (IBETX)*

Interference and Bandwidth adjusted ETX (IBETX) is a quality link metric that was proposed for wireless multi-hop networks [2]. IBETX is based on three parameters. Firstly, Expected Link Delivery (ELD) that is based on finding the paths with the least expected number of retransmission, such as ETX. It sends a broadcast packet with size of 143 bytes in every second and the calculation is based on a window of 10 seconds.

$$d_{exp}(mn) = d_f \times d_r \quad (56)$$

Equation (56) shows $d_{exp}(mn)$ that denotes the number of required retransmissions on a link between nodes m and n. d_f denotes the delivery ratio in forward direction and d_r denotes the delivery ratio in reverse direction. Secondly, Expected Link Bandwidth (ELB) provides the nominal bit rate to find the best path between two nodes among a set of contending links. The nodes could be on a source-destination path P or on a non source-destination path NP but in the same contention domain [2].

$$b_{exp}(mn) = \frac{1}{\sum_{i \in P \cap NP} \frac{1}{r_i}} \quad (57)$$

Equation (57) shows b_{exp} calculation where r_i is the transmission rate of the link i in the domain $(P \cap NP)$, P denotes the source-destination paths and NP denotes to non source-destination paths. b_{exp} encounters the longer paths that are ignored by ETX and other ETX-based metrics [2].

Third is the expected interference of the link that is calculated based on MAC information. DCF periodically probes the MAC to collect the information regarding the times that the link is busy (T_{busy}), time Request To Send (T_{RTS}), time Clear To Send (T_{CTS}), time of receiving packet (T_{Rx}) and time of sending packet (T_{Tx}).

$$i_m = \frac{T_{busy}}{T_t} \quad i_m = \frac{T_{Rx}+T_{RTS}+T_{CTS}}{T_t} \tag{58}$$

$$i_n = \frac{T_{Tx}+T_{Rx}+T_{RTS}+T_{CTS}}{T_t} \tag{59}$$

$$i_{mn} = Max(i_m, i_n) \quad I_{exp} = \frac{i_{mn}}{(1+i_{mn})} \tag{60}$$

Equations (58)-(60) show how to calculate I_{exp}. The IBETX is calculated based on three parameters; d_{exp}, b_{exp} and I_{exp} as shown in equations (56), (57), (60) respectively [2].

$$IBEXT = \frac{d_{exp}}{b_{exp}} \times I_{exp} \tag{61}$$

Equation (61) shows IBETX calculation that as a cross-layer metric, uses the MAC layer information to maximise its throughput. It also avoids increasing the overhead by computational complexities [2]. It finds the quality links from all active links to consider longer paths to give higher throughputs.

G. Summary of Traffic-Aware Metrics

Table 2 shows the comparison of different metrics in this category. Most of the essential parameters considered have been described in table 1. New parameters which were not mentioned in table 1 are described below: (*i*) *Link Traffic Aware* is the parameter that shows which metric aware of traffic on the communication links. (*ii*) *Inter-Flow and Intra-Flow* are the parameters that show the metrics that consider interference on the communication channel link. (*iii*) *Transmission Contention Degree* shows the metrics that take into the account the amount of communication between the nodes in each link. (*iv*) *Nominal Bit Rate Aware* shows metrics that the value of bit rate is calculated in cost of each path. (*v*) *SNR and SNIR aware* shows metrics that observe Signal-to-Noise Ratio (SNR), Signal to Interference and Noise Ratio (SINR) and measure them in link cost. (*vi*) *Load Balancing Capability* shows the metrics that are able to manage load balancing through the network paths.

Table 2. Traffic-aware metrics comparison

Traffic-Aware Metrics Comparison Table						
Metrics Characteristics	DBETX	EAB	EDR	MF	ELP	IBETX
Calculation Complexity (Simple)1,2,3,4,5(Complex)	4	3	4	3	3	3
Packet loss probability	√	√	√	√	√	√
Link Interface specification		√	√		√	√
Bandwidth Aware		√	√			√
Inter-Flow Interference				√	√	√
Intra-Flow Interference		√	√	√	√	√
Mac-layer Retransmission Value	√	√	√	√	√	√
Multi-Rate Links Support		√	√			√
Transmission Contention Degree			√		√	
Longer Path Support			√		√	
Nominal Bit Rates Aware	√					√
SNR & SINR aware	√					
Using Mac-layer Information	√	√	√	√	√	√
Load Balancing Capacity				√		
Asymmetry in Link		√			√	

In summary, DBETX monitors variation on channel and selects paths with lower packet loss probability. It uses SNIR, BER and PER to calculate link quality metric. EAB uses ETX properties and bandwidth occupancy. EDR take into account, packet loss probability, waiting time in queue and transmission interference. MF uses backoff stages for transmission failures and link capacity. ELP uses weighted parameters for forward and backward and interference factor. IBETX is calculated based on interference, bandwidth and packet loss probability.

V. METRICS FOR MULTI CHANNEL NETWORKS

Most of the traditional metrics do not support multi channel networks and they do not provide an acceptable performance in multi channel environment. Multi channel metrics should collect information about all links in all channels and also they should take into account the channel switching cost in case of changing the current communication channel.

A. Exclusive Expected Transmission Time (EETT)

Exclusive Expected Transmission Time (EETT) [16] has been published for supporting large-scale multi-radio mesh networks where traffic travels much longer than small scale networks. Channel distributions on long paths make a significant impact on the throughput performance. EETT is an interference aware routing metrics that select multi channel routes while minimizing interference for high end-to-end throughput [16].

$$EETT_i = \sum_{link\ i \in IS(l)} ETT_i \quad (62)$$

Equation (62) shows EETT calculation where *IS*(*l*) is the interference set of link *l* [16]. EETT as a routing metric in large-scale multi-radio mesh networks reflects on the intra-flow interference. It calculates the ETT of the links in all channels and selects the best path to the destination based on best throughput. It does not take into account the cost of channel changing and it has also the Pros and Cons of ETT. EETT does not consider the longer paths due to its inability to calculate the interferences within the whole neighbours links.

B. Expected ThroughPut (ETP)

Expected ThroughPut (ETP) [3] as a MAC-aware routing metric takes into account the bandwidth sharing mechanism of IEEE802.11 DCF and considers that slow links may degrade the throughput of neighbouring fast links. ETP calculates the throughput estimation more accurately by considering the bandwidth sharing than previous metrics [3].

$$b_k = \frac{1}{(\sum_{j \in (S_k \cap P)} \frac{1}{r_j})} \quad \mathrm{ETP(k)} = \frac{P_k^f \times P_k^r}{(\sum_{j \in (S_k \cap P)} \frac{1}{r_j})} \quad (63)$$

$$f(P) = min_{k \in P} ETP(k) \quad (64)$$

Equations (63) and (64) show how to calculate ETP where *P* is candidate path and *k* is a link in path *P*. S_k is contention domain on link *k* or in other word; they are nodes within communication range of this node. $S_k \cap P$ is the set of links on Path *P* that contend with link *k*. r_j is the nominal bit rate of link *j* and b_k is expected bandwidth received by link *k*. ${P_k}^f$ is packet success probability of link *k* in forward direction and ${P_k}^r$ is in reverse direction. Finally *f*(*P*) is throughput of the link *k* and routing policy chooses the path with the highest routing metrics to maximize the throughput [3].

ETP is based on measuring links expected throughput that captures bandwidth sharing mechanism of 802.11 DCF. This mechanism is more accurate than technique used in ETX, ETT and EDR. ETP is more efficient to use spatial through the long paths than ETX and ETT. ETP is suitable for use in multi-rate and multi-radio networks although it does not have any mechanism to counter interference that causes bottleneck in the network [3].

C. Interface Delay Aware (IDA)

Interface Delay Aware (IDA) [15] metric has been proposed for multi interface WMNs. IDA takes into account inter-flow and intra-flow interference within two nodes. IDA integrates packet loss, transmission ratio and transmission delay as a metric to choose the best path. IDA selects the path with minimum interference and transmission delay to forward packets [15].

$$IDA(p) = (\alpha \times ETD(p)) + (\beta \times CLI(p)) + CSLC(p) \quad (65)$$

Equation (65) shows *IDA* calculation where *CLI*(*p*) is the summation of the traffic load transmission time of all interfering neighbours within two hops for each link along path *p* and *CSLC*(*p*) is channel switching load cost. α and β are balanced parameters to adjust the impact of the difference in the magnitude of the three components of IDA [15].

$$ETD(p) = \frac{TD(p)}{(1 - PL(p))} \quad (66)$$

Equation (66) shows *ETD*(*p*) calculation where it is an estimate of end-to-end delay along path *p*, *TD*(*p*) is the transmission delay of a packet along path *p* and *PL*(*p*) is the packet loss ratio [15].

$$PL(p) = 1 - \prod_{link\ l \in P} (1 - PF_l) \times (1 - PR_l) \quad (67)$$

Equation (67) shows *PL*(*p*) calculation where PF_l and PR_l denote the packet loss probability of the link *l* in forward and reverse directions, respectively [15].

IDA as a multi-interface and multi-channel routing metric in WMN integrated inter-flow interference, intra-flow interference, transmission delay, packet loss ratio and transmission rate in a single metric. IDA has the capability of load balancing and significant congestion avoidance [15].

D. Bottleneck Aware Routing Metric (BATD)

Bottleneck Aware Routing Metric (BATD) takes into account intra-flow interference, link loss rates and diverse data transmission rates within a path. In this metric, the total transmission delay of each independent channel within one path of the links with the same carrier sense range is measured and the largest amount of the transmission delay is considered as the bottleneck channel in the path.

$$BATD(p) = \begin{cases} max(ETD_1, ETD_{12}, ETD_k) \\ ETD_c = \sum_{i=1}^{N_c} ETT_i \quad 0 \le c \le k \end{cases} \quad (68)$$

Equation (68) shows *BATD* calculation where k is the number of channels in path p and ETD_c is the expected time transmission delay for channel c on path p. N_c is the number of links on channel c with path p within the same carrier sense range [35]. BATD is very similar to EETT except it has a mechanism to avoid paths with congestion. The largest amount of transmission delay shows paths with congestion and BATD considers them as bottle neck and avoids using those paths.

E. Improved Bottleneck Aware Transmission Delay (iBATD)

The original BATD metric is based on total transmission delay time in a multi radio network. The Expected Transmission Delay (ETD) in each channel is computed as the total ETT values of links within the same carrier sense range. The ETT value for each individual link is calculated by $\frac{S}{B}$, where S represents the frame size and B denotes the data rate. As $\frac{S}{B}$ does not take into account the MAC layer overhead along with each packet transmission, the BATD could be improved by Improved Bottleneck Aware Transmission Delay (iBATD) [35] to increase the accuracy by using improved ETT (iETT) value instead of ETT. The iETT calculates the discrepancy of link loss rates within one path including MAC layer overheads in expected packet transmission time. iBATD is also more accurate than BATD in detecting bottleneck links.

$$iBATD(p) = \begin{cases} max(ETD_1, ETD_2, , ETD_k) \\ ETD_c = \sum_{i=1}^{N_c} iETT_i \quad 0 \le c \le k \end{cases} \quad (69)$$

Equation (69) shows *iBATD*(p) calculation where k is the number of channels in path p and ETD_c is the expected time transmission delay for channel c on path p. N_c is the number of links on channel c with path p within the same carrier sense range [35].

$$iETT = \sum_{i=1}^{n}(a_i x + b_i) \times (ETX_i) + LID_1 \quad (70)$$

Equation (70) shows *iETT* calculation where x is the frame size in byte and a,b are parameters that are calculated based on data rates and MAC layer modulation. LID_1 is an approximate value of the extra delay caused by the discrepancy between the link with the highest loss rate and the link with the lowest loss rate [35].

$$LTD_1 = [max_{1 \le j \le n}(P_j) - min_{1 \le k \le n}(P_k)] \times (a_i x + b_i) \quad (71)$$

Equation (71) shows LTD_l calculation where $max(P_j)$ represents the maximum loss rate and $min(P_k)$ stands for minimum loss rate in the entire path within one channel [35]. iBATD as a multi-channel, multi-rate routing metric evaluates the bottleneck transmission time more accurately based on considering the MAC layer overhead and the loss rate discrepancy within one path for each individual non-overlapping channel. iBATD metric shows better performance in average network throughput and reduced average packet latency when compares with BATD [35].

F. Metric of Interference and Channel-switching (MIC)

MIC [6] calculation is shown in equation (72).

$$MIC = \frac{1}{N_n \times min(ETT)} \sum_{i=1}^{N} IRU_i + \sum_{i=1}^{N} CSC_i \quad (72)$$

In equation (72), N is the number of links in the path, N_n is the total number of nodes in the network and *min*(*ETT*) is the minimum ETT which represents the minimum transmission rate of wireless interfaces. *IRU* is Interference-aware Resource Usage that is calculated based on ETT multiply by number of neighbour and CSC is Channel Switching Cost which is equal to w_1, if the channel is changed or equal to w_2, if the new channel is the same with the previous one [35].

$$IRU_i = ETT_i \times N_i \quad (73)$$

$$CSC_i = \begin{cases} w_1 & previousnodechannel \ne choosenchannel \\ w_2 & previousnodechannel = choosenchannel \end{cases}$$

$$0 \le w_1 \le w_2 \quad (74)$$

Equations (73) and (74) show how to calculate IRU_i and also CSC_i where N_l is the number of links neighbours, ETT_l is *ETT* of each link and IRU means the aggregated channel time of all nodes in the area which are used for transmission [36]. MIC uses the links that use the channel less. By using links with less usage, the inter-flow interference takes into metric calculation. In CSC, if the previous node in routing path use the same channel, the cost will be w_2 and if the channel of the current node is different from previous nodes channel in routing path, then CSC is equal to w_1. The cost will be more if the channel is the same. The protocol chooses the paths with using multiple channels through the route for the reason of avoiding intra-flow interference. MIC takes intra-flow interference into the metric calculation [36]. MIC does not consider the interference of nodes when they are in radio frequency range but in data transmission range. The interference range is always much larger than the transmission range and this makes MIC less realistic because transmission on a link could makes interference on another link although it is not in its transmission range [36].

G. Weighted Cumulative ETT (WCETT)

WCETT [16] is one of the routing protocols metric that considers channel diversity in multi channel networks.

$$WCETT = (1-\alpha)\sum_{i=1}^{N} ETT_i + \alpha max_{i\le j\le k}(X_j) \quad (75)$$

Equation (75) shows WCETT calculation where α is a tuneable parameter to balance the weights and X_j is the number of times that channel j is used or experienced intra-flow interference. N is the number of links and K is number of channels. WCETT takes intra-flow interference into account but not inter-flow interference [9]. WCETT gives low cost to the paths that use more diversified channels with less intra-flow interference [6]. It also does not calculate the minimum path cost as this metric is not isotonic and it makes WCETT unusable in link-state routing protocols. It can be used in Link Quality Source Routing (LQSR) that is on-demand routing or in other distance vector routing [16].

H. Weighted Hop, spectrum-Awareness and sTability Metric (WHAT)

WHAT [17] selects high performance end to end path in multi-hop cognitive wireless networks [17]. In a cognitive wireless networks, finding a path based on time-varying spectrums and status of primary users is more difficult than traditional networks. WHAT takes into account the opportunistic spectrum access and path stability by synthesizing channel switching frequency, usage of licensed channels and paths length to evaluate the quality in an end-to-end path [17].

WHAT uses three assumptions, first; every node has at least two cognitive radio equipments, one of them is used for control and routing management and the second one is used for data transmission. The second radio equipment uses all licensed and unlicensed channels. The control radio equipment works on Common Control Channel (CCC) and it is responsible to scan the channels. Second; the system uses a non-interference unlicensed channel for the CCC and N non-interference licensed channels with the same bandwidth for data transmission. Third; every node has the capability to sense each channel and usage history. Nodes use Cognitive MAC (CMAC) to negotiate channel synchronization and communication with neighbours. This information from cognitive radios are used in processing of the routing protocols [17].

$$\sqrt{D(U_i)} = \sqrt{\sum_{f}^{f\in S_i}(((P(U_i^f) - E(U_i))^2) \times P(U_i^f))} \quad (76)$$

$$WHAT(L) = \sum_{i}^{i\in L}\frac{1}{(1-\beta)\times\sqrt{D(U_i)}+\beta\times\sum_{f}^{f\in S_i} p(U_i^f)+1} \quad (77)$$

Equations (76) and (77) show calculation of WHAT that uses a tuning parameter β to weight two parts of equation, standard deviation of a node along a path and the total usage of the licensed channels used in the next hop node along the path. L is set of channels that are available for node i and $S_{i,j}$ is set of licensed channel between nodes i,j and $\mathbf{p}(U_i^f)$ is the percentage of usage of channel f by node i and $E(U_i)$ is the average usage of channels by node i and $\sqrt{D(U_i)}$ is standard deviation of all channels that are used by node i, L is end-to-end path [17].

WHAT is based on finding a stable and well-performed path for TCP with isotonicity and monotonicity simultaneously. WHAT has observed channel switching frequency, usage of licensed channels, and path length to calculate the overall cost of a path. The results show that WHAT can improve TCP throughput significantly [17]. WHAT is compatible with cognitive radio technologies.

I. interference aware routing metric (iAWARE)

interference AWARE routing metric (iAWARE) [10] metric has been presented to assist routing protocols for multi radio infrastructure mesh networks where nodes use multiple radio frequency interfaces. By using this metric, the best path will be chosen based on reducing inter-flow and intra-flow interference. This metric aim is to find paths with links that experience low loss ratio, high data rate and low level interference [10]. The protocol uses links interference experiences to capture the potential of interference in the network and chose the paths with less interference while improving the overall network throughput [10].

In this model, the communication between node *u* and *v* is successful if the SINR at the receiver *v* is above a certain threshold. The level of threshold depends on channel characteristic, data rate and other transmission parameters. $P_v(u)$ denotes the signal strength of a packet from node *u* at node *v*.

$$\frac{P_v(u)}{N+\sum_{w\in V'} P_v(W)} \leq \beta \quad (78)$$

Equation (78) shows the condition where β is a constant that depends on data rate, channel parameters and modulation schemes [10]. *N* is background noise, *v* is the set of nodes which could simultaneously transmit in this metric. Interference ratio *IR* is calculated by:

$$IR_i(u) = \frac{SINR_i(u)}{SNR_i(u)} \quad (79)$$

$$SNR_i(u) = \frac{P_u(v)}{N} \quad (80)$$

$$SINR_i(u) = \frac{P_u(v)}{N+\sum_{w\in\eta(u)} \tau(w) P_u(w)} \quad (81)$$

Equations (79)-(81) show IR_i calculation where $\eta(u$ denotes the set of nodes which node *u* can receive signal from, $\tau(w)$ is the normalized rate at which node *w* generate traffic averaged over a period of time. $\tau(w)$ weights the signal strength based on interfering node \$w\$. It gives the fraction of time node *w* use the channel [10].

$$IR_i = min(IR_i(u), IR_i(v)) \quad (82)$$

Equation (82) shows IR_i calculation where *i* is bidirectional communication link (*u*,*v*) [10].

$$iAWARE_j = \frac{ETT_j}{IR_j} \quad (83)$$

$$iAWARE(p) = (1-\alpha) \times \sum_{i=1}^{n} iAWARE_i + \alpha \times max_{1\leq j\leq k} X_j \quad (84)$$

$$X_j = \sum_{conflictinglinkionlinkj} iAWARE_{i,1\leq j\leq k} \quad (85)$$

Equations (83)-(85) show iAWARE calculation that as a multi-radio and interference aware routing metric tries to find paths with less inter-flow and intra-flow interference [10]. The results in [17] show that iAWARE considers changes in interfering traffic thereby delivering higher throughput with better channel diversity. *iAWARE*(*p*) is a non-isotonic metric such as WCETTT [10].

J. Multi Channel Routing (MCR)

Multi Channel Routing (MCR) [37] metrics has covered the gap of routing metrics for supporting multi channel and multi interface networks. It has been proposed as a link layer protocol to manage multiple channels over IEEE 802.11. In multi-interface concept, the available interfaces are classified in two different types; *Fixed interface*, denotes the interface which works in specific fixed channel and *Switchable interface* that can switch between different channel more frequently [37].

MCR selects channel with diverse routes based on taking the interface switching cost into the cost link. MCR is a version of WCETT which was designed for nodes that the number of usage channels is equal to interface number. MCR was designed for the networks where the number of available interfaces may be smaller than available channels and by interface switching, all the channels can be utilized [37].

$$P_s(j) = \sum_{\forall i\neq j} InterFaceUsage(i) \quad (86)$$

Equation (86) shows P_s calculation where *InterfaceUsage*(*i*) is the fraction of time that a switchable interface is busy transmitting on channel *i* [37]. $P_s(j)$ is the probability that the switchable interface is on a different channel (*i*≠*j*) when a packet arrives on channel *j*.

$$SwitchingCost(j) = P_s(j) \times SwitchingDelay \quad (87)$$

Where SwitchingDelay is the latency in switching between interfaces.

$$ETT = ETX \times \frac{S}{B} + SwitchingCost(i) \quad (88)$$

$$X_j = \sum_{\forall isuchthati^{t}hhopuseschannelj} ETT_i \quad (89)$$

$$MCR = (1-\alpha) \times \sum_{i=1} nETT_i + \alpha \times max_{1\leq j\leq c} X_j \quad (90)$$

Equation (87)-(90) show MCR calculation where α is weighting parameters between 0 and 1, *n* is the number of hops on the path and *c* is the total number of available channels. MCR is weighted in two part, first part increases the cost by using more hops in the path and second part increases if channel diverse paths are not selected [37]. MCR as a metric for multi-channel, multi-interface networks uses the available channels even if the number of interfaces per host is smaller than the number of available channels. Results in [37] show the network capacity can be significantly improved by using MCR.

K. Cross Layer Interference-Load and Delay Aware (CL-ILD)

Cross Layer Interference-Load and Delay Aware (CL-ILD) is a cross layer routing metric that take into the calculation, interference, load and delay for multi-channel acWMNs. SNR and SINR are used in interference model in links in WMNs [38].

$$CL-ILD(p) = \alpha \times \sum_{link\ l\in p}^{n} INLD_i + \beta \times \sum_{node\ j\in p}^{n} CD_i \quad (91)$$

Equation (91) shows *CL-ILD* calculation where α and β are constant and they are between 0 and 1. *n* is the number of links and *m* is the number of nodes in the path *p*. *INLD* is the Inter-flow interference, Load and Delay component and *CD* is Channel Diversity that calculated based on intra-flow interference [38].

$$ILD_i = (1 - IR_i \times C_n) + ETT \quad (92)$$

where $0 \leq IR_i \leq 1$ and $0 \leq C_n \leq 1$

Equation (92) shows *ILD* calculation where IR_i denotes inter-flow interference based on the ratio of SINR and SNR that the calculation is described in equation (93) and C_n denotes Channel utilization that is describe in equation (94). Both IR_i and C_n have values between 0 and 1 [38].

$$IR_i = \frac{SINR_i}{SNR_i} \quad (93)$$

Equation (93) shows IR_i calculation where based on SINR and SNR values [38].

$$C_n = 1 - \frac{Idletime}{totaltime} \quad (94)$$

Equation (94) shows C_n calculation where *Idletime* denotes the time that the channel is not busy and *totaltime* denotes the time of monitoring channel [38].

$$ETT = ETX \times \frac{S}{B} \quad (95)$$

Equation (95) shows ETT calculation where ETX is expected number of retransmission, *S* denotes to packet size and *B* denotes available bandwidth [38].

$$CD_i = \begin{cases} W_1 & C_{i-1} \neq C_i \\ W_2 & C_{i-1} = C_i \end{cases} \quad 0 \leq W_1 \leq W_2 \quad (96)$$

Equation (96) shows CD_i calculation where C_i denotes the channel is used by node *i* and also C_{i-1} is channel used by node *i*-1 and W_1 and W_2 are the weights [38].

L. Cumulated Interference Metric (CIM)

Cumulated Interference Metric (CIM) [39] is multi-channel metric that take to account the inter-flow and intra-flow interferences and also link quality. CIM selects high throughput path with low interferences by using different channels [39].

$$CIM_n(i,j) = ETX(i,j) \times \frac{S}{IBR_n(i,j)} \quad (97)$$

Equation (97) shows $CIM_n(I,j)$ that is CIM node between *i* and node *j* in channel *n* calculation where *S* denotes the packet size and IBR denotes Interferer-link Bit Rate [39].

$$IBR_n(i,j) = \frac{r_n(i,j)}{|S_n(i,j)|+1} \quad (98)$$

Equation (98) shows *IBR* calculation where $r_j(i,j)$ represents the bit rate of the link between nodes *i* and *j* in channel *n* and $S_n(I,j)$ denotes the shared bit rate in channel *n* [39].

$$X_n = \sum_{link(i,j)\in Pusingchanneln} CIM(i,j) \quad (99)$$

Equation (99) shows *X* calculation where *P* in total path [39].

$$CIM(P) = (1-\beta)\sum_{link(i,j)\in P} CIM(i,j) + \beta max_{I\leq n\leq k} X_n \quad (100)$$

Equation (100) shows CIM calculation where *k* is number of channels [39].

M. Multi-Radio Optimized Link State Routing (MR-OLSR)

Multi-Radio Optimized Link State Routing (MR-OLSR) [40] is a multi-radio or multi-channel optimized link state that is improved version of OLSR. It diverse data traffic through multiple paths to avoid links with congestion and also improve channel throughput substantially. MR-OLSR uses Improved Weighted Culminated Estimate Transfer Time (IWCETT) as link quality metric and also by using channel allocation strategy and path scheduling algorithm offers load balancing in multi-channel networks [40].

$$CI = \frac{IFQ_A^j}{B} \quad (101)$$

Equation (101) shows CI as Congestion Indicator calculation where IFQ_A^j denotes the data queue in the node A on channel j and B denotes the bandwidth [40].

$$CI_{A-B}^j = CI_A^j + CI_B^j + \sum_{W\in(Nb_A)\cup W\in(Nb_B)} CI_W^j \quad (102)$$

Equation (102) shows CI calculation between nodes A and B where Nb_A denotes neighbours of node A and where Nb_B denotes neighbours of node B. W denotes to any nodes that are in neighbours nodes A and B [40].

$$LL_{A-B}^j = (1-\gamma)\times ETT_{A-B}^j + \gamma \times CI_{A-B}^j \quad (103)$$

Equation (103) shows LL calculation as Link Load between node A and node B where γ is smooth factor [40].

$$X_j = \sum_{Hop\ i\ in\ channel\ j} LL_i \quad 1 \le j \le k \quad (104)$$

Equation (104) shows X_j as the total of transmission time for multi-hop on channel j calculation where LL_i is link load in node i [40].

$$IWCETT = (1-\beta)\times \sum_{i=1}^{n} LL_i + \beta \times max_{I\le j\le k} X_i \quad (105)$$

Equation (105) shows IWCETT calculation where β is a weighted parameters that balance link load and delay parts [40].

Table 3. Multi-channel metrics comparison

Multi-Channel Metrics Comparison Table													
Metrics Characteristics	EETT	ETP	IDAR	BATD	iBATD	MIC	WCETT	WHAT	iAWARE	MCR	CL-ILD	MR-OLSR	CIM
Calculation Complexity (Simple)1,2,3,4,5(Complex)	2	4	3	3	3	3	3	3	4	4	4	4	4
Packet loss probability	√	√	√	√	√	√	√			√	√	√	√
Link Interface specification	√		√	√	√	√	√		√	√	√	√	√
Link Traffic Aware			√						√	√	√	√	√
Bandwidth Aware	√	√		√	√	√	√		√	√	√	√	
Probe Size	√			√	√	√	√			√	√		√
Inter-Flow Interference			√						√		√	√	√
Intra-Flow Interference			√	√	√		√	√	√	√	√	√	√
Multi Channel Support	√	√	√	√	√	√	√	√	√	√	√	√	√
Channel Switching Cost						√		√		√			
Mac-Layer Retransmission Value	√	√	√	√	√	√	√			√			√
Multi-Rate Links Support	√	√	√	√	√	√	√		√	√			
Longer Path Support							√						
Interface Switching Cost			√			√				√			
Nominal Bit Rates Aware		√											
SNR & SNIR Aware									√		√		
Using Mac-Layer Information	√	√	√	√	√	√	√	√		√	√	√	√
Transmission Delay Aware	√		√	√	√	√	√			√	√	√	

N. *Summary of Multi-Channel Metrics*

Table 3 shows the comparison of different multi channel metrics. Most of the essential parameters considered have been described in tables (1), (2). New parameters which were not mentioned before are described below: (*i*) *Multi Channel Support* shows the metrics that could be used in multi frequency environment with different interfaces. (*ii*) *Channel Switching Cost* shows the metrics that consider the cost of switching channel in metric calculation. (*iii*) *Interface Switching Cost* shows the metrics that take into the account the cost of changing the interface to transmit the packets.

In summary, EETT is an ETT version for multi channel environments. ETP is more accurate than ETX, EDR and also ETT and is based on bandwidth sharing and estimating the throughput. IDA finds best paths based on minimum interference and delay. BATD takes into account interference, link loss rate and transmission delay. iBATD is based on discrepancy of link loss rate and MAC layer overhead. MIC uses ETT and takes channel switching cost into the calculation of link quality metrics. WCETT also uses ETT parameters and channel experience of intra-flow interference. WHAT monitors channel switching frequency and usage of licensed channels. iAWARE uses ETT characteristics and signal strength and background noise by using SNR and SINR. MCR also uses ETT plus interference usage and switching cost. CL-ILD uses delay and load baseds on intra-flow and inter-flow interferences plus load at MAC layer. MR-OLSR is a multi-channel version of OLSR with load balancing feature that takes into account the link load and also inter-flows interference. CIM chooses the best path based on low inter-flow and intra-flow interferences in different channels.

VI. CONCLUSION

In this work, we studied most of routing protocol metrics in Wireless Mesh Networks and the specifications of each metrics have been described in detail. The metrics in general have been considered as link quality and traffic aware metrics. In link quality metrics, mETX is a modified version of ETX that is based on average and variance of the error probability. ENT as the next version of mETX which takes into account the visibility of packet loss for upper layers protocols are more popular metrics in this category. In traffic aware metrics, EDR as a load insensitive metric which is based on a transmission interference model in IEEE 802.11 medium access control protocol and it is used in many routing protocols. In multi channel networks, iAWARE as a multi channel metric finds paths with links with low loss ratio, high data rate and low level interference experience. MCR as a version of WCETT is suitable for networks where the number of available interfaces may be smaller than available channels. WHAT is a metric suitable for cognitive radio environment that selects high performance end to end path in multi-hop cognitive wireless mesh networks.

ETX-Embedded, SERM and mETX are suitable metrics for low power devices like WSN. MTM as a multi-rate metric is a suitable and effective routing metric that avoid long distance paths while ETP is an accurate metric suitable for long paths. IBETX and IDA are more sophisticated metrics that take most of the parameters of link quality into the calculation of path cost. ETD as multi-channel metrics considers interferences, delay, packet loss and congested path in its calculation and it is more accurate metrics for multi-channel environment.

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Fariborz Entezami Fariborz Entezami is currently a PhD candidate at the Faculty of Science, Engineering and Computing (SEC), School of Computing & Information Systems (CIS), Kingston University, London, UK. He received the BSc. Engineering degree in Electrical Engineering from the Iran University of Science and Technology (IUST) Tehran, Iran and also received MSc in Industrial Management in Industrial Management Institute (IMI), Tehran, Iran. He received another MSc in Networking and Information security at the faculty of SEC, Kingston University London, UK in 2011. He also works in Wireless Multimedia & Networking (WMN) Research Group and currently researching on routing protocols in Mobile ad-hoc and Wireless Sensor Networks (WSNs) as well as giving the occasional lecture on various subjects within the networking realm within the SEC faculty. Ho also has contribution to the EU-FP7 ICT PROACTIVE project. He has experience in networking and IT industries for years in management and consultant levels. He is a member of the IEEE.

Christos Politis Christos is an Associate Professor (Reader) of Wireless Communications at Kingston University London, Faculty of Science, Engineering & Computing (SEC). There he heads a polycultural and dynamic research group called Wireless Multimedia and Networking (WMN) and teaches courses on wireless systems and networks. Prior to this, Christos worked for Ofcom, the UK Regulator and Competition Authority, as a Senior Research Manager. While at the University of Surrey, UK, he undertook a postdoc working on virtual distributed testbeds in the renowned Centre for Communication Systems Research (CCSR). This was preceded by placements with Intracom Telecom, Athens and the Hellenic Air Force (HAF) in Greece. Christos has managed to raise several millions of funding from the EU and UK research/ technology frameworks under the ICT and Security programmes. He holds two patents and has published more than 150 papers in international journals and conferences and chapters in six books. He is actively involved with technology start-ups. Christos holds a PhD and MSc from the University of Surrey, UK and a B.Eng. from the National Technical University of Athens, Greece. He is a senior member of the IEEE and IET and the Technical Chamber of Greece.