Survey of Recent Routing Metrics and Protocols for Mobile Ad-Hoc Networks

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Abstract —In recent years, research on advancing performance of mobile ad-hoc networks (MANETs) has attracted a special attention of scientists around the world. In a dynamic network environment like MANET, routing protocols play a particularly important role in improving the overall network performance. In essence, each routing protocol may use a combined routing metrics to select the intended route(s) for data transmission. This means that routing metrics will influence the design of routing protocols for MANETs. Therefore, we investigate on routing metrics and protocols proposed for MANETs. Our main focus will be on proposals aimed at high achievable network performance and energy efficiency. In this paper, we summarize our findings and propose future research directions.

Index Terms—MANET, metric, routing, protocol, high performance, energy efficiency

I. Introduction

Nowadays, with the robust development of mobile communications systems, global mobile data traffic has increased 18 times in the past five years, accounting for 63% of global network traffic, with over 8 billion mobile devices connected to the network. The Cisco VNI 2017 (Cisco Visual Networking Index 2017) predicts that by 2021, global mobile data traffic will increase by more than seven times the current level, with over 11.6 billion mobile devices joining the network and video traffic will account 3/4 of global network traffic [1]. Therefore, designing faster, energy-efficient mobile networks are necessary. Mobile Ad-hoc Networks (MANETs), launched in the 1970s, are a set of mobile devices that are capable of self-configuring, establishing, and communicating with each other without relying on base stations [2]. The flexibility in setting up and transmitting data allows MANETs to have a wide range of applications [3], [4], (see Fig. 1).

Theoretically, the performance of a wireless network depends on its size, communication model and radio environment. However, in a MANET, dynamic routing features of the network make its performance really low. For example, each network node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity and the routing algorithm in use. Thus, routing protocols play a particularly important role in improving the performance of MANETs [5].

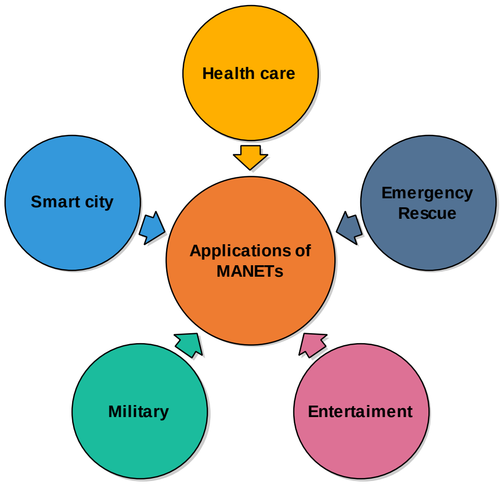

Fig. 1. An illustration of applications of MANETs.

Different routing protocols have been proposed for MANETs. Among them, AODV (Ad-hoc On-demand Distance Vector) and DSR (Dynamic Source Routing) are two most well-known protocols. They use the same routing metric, namely hop-count. However, since the network topology is dynamically changing, the only routing metric like hop-count is not effective [6]. Today, in order to provide robust, reliable, high-performance routing protocols, metrics such as end-to-end delay, throughput, load balancing and battery capacity need to be considered.

In this paper, we survey routing metrics and protocols proposed recently for MANETs. We classify routing metrics according to four different approaches: traffic, radio information, energy and mobility-location. In particular, we enhance the current research directions that concentrate on network performance improvement. Also, we examine all MANET routing protocols, which are published on the IEEE Xplore digital library from 2010 to 2017. The surveyed protocols are divided into four categories including Performance Overall, Quality of Service (QoS), Effective Energy and Security. In each sort, we select some proposals to describe and highlight their objective and main idea. Then, basing on our findings, we propose and discuss possible open research directions.

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II. Performance Factors and Routing Metrics

In this section, we revisit and analyze performance factors as well as key characteristics of routing metrics in MANETs.

A. Performance Factors

The performance of MANETs is constrained by a variety of factors. Normally, we cannot fully identify all of these factors. This problem is known as NP-complete [2], [6]. To simplify, as shown in Fig. 2, we can divide these factors into two main categories: *environmental factors* and *internal factors*.

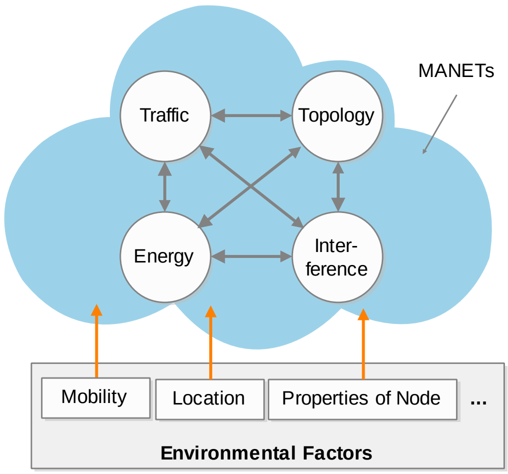

Fig. 2. Factors affecting the performance of MANETs.

Environmental factors, defined as external factors, affect the network performance. In other words, environmental factors are input parameters that cannot be changed (e.g. mobility attributes of the network node, external interference, network setup location, etc.).

Internal factors, defined as direct or indirect factors, are generated by operations of the network. These factors may be network traffic, internal network interference, transmission power, dynamic network structure, etc.

B. Routing Metric Characteristics

A routing metric is a unit calculated by a routing algorithm for selecting or rejecting a routing path for transferring data. We review basic characteristics of routing metrics as follows.

Dimensional metrics: determined by the number of parameters involved in the costing process. Conventional routing protocols such as AODV or DSR use a single-dimensional metric, which is hop-count. Most recent routing solutions introduce multi-dimensional metric (or a metric vector) routing protocols. For instance, the proposal proposed in [3] utilizes a three-dimensional routing metric evolving throughput, current location, and destination location. Multi-dimensional metrics are also called multi metric because they can be decomposed into one-dimensional metric through an equation. For example, in [4], energy, delay and bandwidth are three metrics used. However, they can be combined into a single-dimensional metric through a mathematical function.

Combined metrics: calculated from different routing metrics through a mathematical equation. A good example is the mobility factor metric [5]. This metric is based on the combination of velocity, direction, and pause time metrics of the node.

The layer providing information: this feature describes layers of the OSI model that provide information to calculate the metric. Traditionally, routing metrics are only determined by the information in the network layer. Recently, many studies have proposed cross-layer routing approaches (e.g. energy-efficient routing protocols can be based on routing information provided by the physical layer [7]).

Methods of receiving routing information: there are many ways to obtain routing information. Below are four of them:

+ *Node-related*: routing information is provided by network nodes, which may be fixed values such as the interface number of a node, or the variable values such as the queue length and the remaining battery power of the node.

+ *Passive mode*: this method gathers passive routing information (i.e. available bandwidth of a link) by monitoring the incoming and outgoing traffic of a network node.

+ *Active probing*: this method creates special packets to measure different properties of a link. For example, in [14] the method is deployed to determine the reliability of a link. As a result, the ETX (Expected Transmission Count) metric can be obtained.

+ *Piggy-back probing*: The measurement is performed by inserting probe information into regular traffic or routing packets without creating special packets. This is a common method for calculating the routing cost of a route. At each node, the metric of each link will be calculated and inserted into the header of control packets, such as RREQ (Route Request) and RREP (Route Reply), to provide information for the node. Then, the route selection decision is made accordingly [9].

C. Selection of Routing Metrics

In general, the selection of routing metrics depends on the designed goals of a network. We can separate these goals into two types as follows:

Main goals: Routing metrics must satisfy basic QoS requirements in MANETs.

Optimizing goals: In addition to the main goals, routing metrics must also satisfy the goals required by each application, such as QoS, high performance and energy efficiency. Clearly, MANETs with different goals will need to use different routing metrics. For example, a real-time video application needs a low latency, so it is necessary to involve the delay metric into route cost calculation process.

D. Performance Evaluation

Quantitative and effective evaluating routing metrics and protocols are complex tasks that depend on various factors such as the type of applications, routing protocols, and scenarios performed (i.e. location, node number, mobility and capacity of nodes, etc.). For this reason, the simulation results based on some restricted assumptions will not give a complete evaluation. A real evaluation can not be done by conducting experiments on all dedicated applications, models, scenarios, even not in the real environment. Therefore, in the next sections we limit our analysis and discussion to metrics mentioned in [2].

III. Review of Routing Metrics

In this section, we present our findings on routing metrics. The routing metrics can be divided into four groups, that are: traffic-based, radio information, energy and location-mobility. Details will be given in the sub-sections below.

A. *Traffic-based Metrics*

There exist various communicating applications in MANET environments having network traffic-related quality of service requirements (e.g. delay, throughput, reliability and quality of links). Clearly, traffic-based routing metric approach is effective and many metrics have been suggested under this orientation (see Fig. 3).

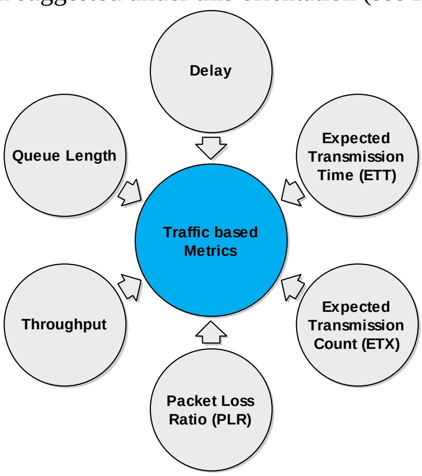

Fig. 3. Routing metrics based on the traffic approach.

1) *Delay metric*

Delay of a link is determined by measuring the time intervals when sending and receiving a packet between two neighboring nodes. There are two ways to perform this measurement: Active probing and Piggy-back probing. Delay may consist of six different phases: queue delay (Q_S, Q_R), processing delay (P_S, P_R), transmission delay T, and propagation delay P. We assume that the bandwidth between two nodes (i, j) is B, the transmission delay of a packet in b bit size is T, $T = B/b$. Then, the overall delay $D_{i,j}$ can be determined as follows:

$$D_{i,j} = P_S + Q_S + P + \frac{B}{b} + Q_R + P_R \quad (1)$$

Suppose that $D_{i,j}$, $D_{j,k}$ respectively are the delays of hops (i, j) and (j, k). The overall delay of the connection (i, k), can be determined as follows:

$$D_{i,k} = D_{i,j} + D_{j,k} + 2 \times Cov(D_{i,j}, D_{j,k}) \quad (2)$$

where, $Cov(D_{i,j}, D_{j,k})$ is the covariance of the delays of the above two links. Calculating the covariance of delays becomes more complicated when the number of links increases. To simplify this problem, End-to-End delay is used to measure the delay time of a route [10].

2) *Queue Length*

Each network node has ingress queues and egress queues to store the packets if its network interfaces cannot forward them immediately (see Fig. 4). The queue length plays an important role in determining the time delay when a packet goes through a node. If the queue is empty, the node can receive and process traffic immediately. Otherwise, traffic must be queued for processing. Normally, the queue length of each network node is limited. A network node will not receive additional packets when the queue is full (drop packets). This explains why the queue length have suggested as a routing metric [4], [9].

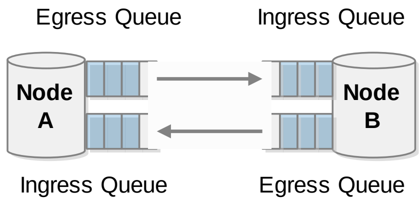

Fig. 4. Queue model of mobile nodes.

3) *Bandwidth*

Bandwidth and its associated routing metrics (i.e. throughput and capacity) determine the ability that data can be sent over a link in a period of time. The bandwidth of a link is equal to the transfer rate of that link. Bandwidth metrics are commonly used, especially for applications that request quality of service [11], [12]. The bandwidth of a route is the minimum bandwidth of links on the route.

$$BW_{route} = \min_{i \in route}(BW_i) \quad (3)$$

A simulation given in [12] proves that routing utilizing the bandwidth metric can increase more than 20% throughput compared with hop-count based routing.

4) *Packet Loss Ratio (PLR)*

PLR is an important indicator for all applications. The high PLR will reduce the quality of communications in applications. In MANETs, physical reasons such as interference and node mobility are the main causes for high packet loss ratios. The PLR of a route can be determined as follows:

$$PLR_{route} = 1 - \prod_{i \in route}(1 - PLR_i) \quad (4)$$

To evaluate the efficiency of PLR metrics, in [13], Yarvis *et al.* setup an experiment with a PLR weighting on each link. Then, their simulation results show that the gained packet loss ratio is better (i.e. ranging from 20% to 32% better than the PLR obtained using the hop-count metric routing).

5) *Expected Transmission Count (ETX)*

ETX is the first metric specifically designed for MANETs. When they realized that the hop count routing method was not effective for MANETs. Couto *et al.* [14] proposed a metric based on packet loss ratio for the purpose of predicting the number of transmissions required (including re-transmission) to successfully transmit a packet on the link. Minimizing retransmissions not only optimizes overall throughput, it also minimizes the total power consumption if we assume that the transmission power is unchanged [15]. Let d_f and d_r, respective, is the probability of transmitting and receiving the success of a packet over a link, ETX on the link l, can be determined, as follows:

$$ETX_l = \frac{1}{d_f \times d_r} \tag{5}$$

The ETX of the path p is equal to the total of ETX on the links, can be determined, as follows:

$$ETX_p = \sum_{l \in p} ETX_l \tag{6}$$

To consider the effect of proposed metric, Couto et al. [14] experimented to compared the performance of two routing metrics, are ETX and hop count. Experimental results show that ETX improves throughput over twice than the hop count metric when the mobility of node is low and decreases as the network increases mobility. In particular, ETX is one of the few metrics actually deployed to make routing metric in the OLSR (Optimized Link State Routing) protocol, which is called OLSRD [16].

Although ETX is determined based on the packet delivery rate, which has directly related to throughput, ETX doesn't consider the throughput indicator of the route. In other words, ETX relies on the reliability of the route without considering the speed of the route. This is the limiting point of ETX.

6) Expected Transmission Time (ETT)

In recognition of some limitations of ETX, Draves et al. [17] proposed the ETT metric, which was improved from ETX metric. Let S is the size of probe packet and B is the bandwidth of the link l. ETT of the link l can be determined, as follows:

$$ETT_l = ETX_l \times \frac{S}{B} \tag{7}$$

The ETT of path p is equal to the sum of ETT on the links, can be determined, as follows:

$$ETT_p = \sum_{l \in p} ETT_l \tag{8}$$

By bandwidth constraints on routing metric, ETT can be selected the best paths and has the highest bandwidth. Draves *et al.* propose using a pair of probe packets to measure the bandwidth per link. Of course, this may increase the network traffic but not significantly.

7) Weighted Cumulative ETT (WCETT)

To improve the performance of MANETs through the multi-channel operation mechanism supported on network interfaces. Draves *et al.* [17] continue to propose WCETT metric with the special purpose of reducing the co-channel interference when network interfaces operate in multi-channel mode. The solution perform is to try to minimize the number of nodes that use the same channel on the entire route. The specific technique is to use an average weight to balance the total cost of the entire route with the effect of the bottleneck channel.

Let k is the total number of channels of the system, X_j là the total transmission time on channel j of the route p, $WCETT$ metric can be determined as follows:

$$X_j = \sum_{i \in p} ETT_i \qquad 1 \le j \le k \tag{9}$$

$$WCETT = (1-\alpha) \times \sum_{i=1}^{n} ETT_i + \alpha \times \max_{1 \le j \le k} X_j \tag{10}$$

To evaluation effective of WCETT metric, Draves et al. [28] perform simulations to comparing the performance of two metrics: WCETT and ETX. The simulation results show that WCETT has superior performance over ETX in all criteria. However, one limitation is that the authors do not indicate how to define the parameter α. By experimental, the authors proposed the value of $\alpha = 0.5$ is the most reasonable. In our view, the problem of determining the α parameter needs to be studied in greater detail in the future in order to further improve the efficiency of WCETT metric.

B. Radio Information

The physical layer of the wireless network nodes in MANETs is much more complex than the wired network. Especially issue interference. This is not only a challenge for the physical layer developers but also affect routing capacity.

1) Signal strength metric

Radio technologies use beacon signals to detect and exchange information with neighboring nodes through the wireless environment. Through this method, the network node can determine the signal strength at the destination node. The signal strength can be viewed as an indication of the quality of the link and the distance between the two nodes. In [18], Dube et al. proposed an SSA (Signal Stability-based Adaptive) routing protocol that uses signal strength metric. Simulation results show that the number of re-establish routes decreases by more than 60% when using signal strength metric replace the hop count metric. The result is clearer when the network density is high. However, the signal strength metric can't be to evaluation overview about the quality of a link.

2) Signal-to-Noise Ratio (SNR) metric

Normally, SNR is used as a measure of channel quality. In theory, SNR is an excellent predictor of the quality of a link [2], [19], but Lampe *et al.* [20] have shown that SNR can only predict the quality of a link best with Gaussian noise.

3) Bit Error Rate (BER) metric

Similar to the SNR metric, the BER metric is determined by the bit error rate and the number of retransmission requests on a link. In other words, this reflects the reliability and energy consumption of the link [21].

In general, the limitation of routing metrics based on this approach is the information must be provided from the lower layers. Therefore, the routing protocol is crossover protocol.

C. Mobility and Location Metric

Routing based on the location of the nodes is the approach to simplify the routing problem in cases where the network nodes can obtain location information (such as when the network node is equipped with GPS - Global Positioning System). Due to the dynamic nature of MANETs, to the efficiency routing, normally, location information is combined with information as velocity and movement direction of the node to can be determined exactly location of the node in real time.

1) Location metric

A survey of the location-based routing protocols for MANETs are showed in [22]. In the location-based approach, the simplest method is to use distance information as the routing metric. However, the fact that, due to mobility and radio wave characteristics, this value is not useful in many cases. Although the distance affects the signal strength, other factors may be more important. In the radio environment, the quality of the link is greatly reduced when it is shielded such as trees or buildings. In this case, the signal strength can reflect the quality of the route is better than the distance. The quality and stability of a link depend very much on the speed of a node. The faster moving nodes will have the higher broken link probability. A technique to determine the speed and direction of movement of a node may be based on information from the GPS (Global Positioning System).

2) Mobility metric

Johansson *et al.* [23] define a routing metric based on node mobility as follows:

Let $l(n,t)$ is the position of node n at time t. Then, the relative velocity of the two nodes x and y at time t can be determined, as follows:

$$v(x,y,t) = \frac{d}{dt} \times (l(x,t) - l(y,t)) \quad (11)$$

Let $M_{x,y}$ is the measure of mobility between pairs of nodes (x,y), determined by their relative speed over a period of time T, we have:

$$M_{xy} = \frac{1}{T} \times \int_{t_0 \le t \le t_0+T} |v(x,y,t)| dt \quad (12)$$

Like as the radio information-based approach, this approaches must be provided information by low network layers or GPS system. Normally, they have the high delay and large device sizes, high energy consumption, and therefore only suitable for some special applications such as the vehicular network.

D. Energy

Due to the mobility characteristics of MANETs, mobile nodes use batteries to store energy. Therefore, energy efficiency is a particularly important issue. Minimizing energy consumption per packet is the most basic approach to energy-based routing metrics. Many energy efficiency solutions for the MANETs have been reviewed in [24].

In this section, we survey the basics issue related to energy consumption in MANETs and then describe the energy based routing metrics. The energy consumption of a node is affected by a number of key factors as follows:

- When the network node transmits or receives a packet (including routing packets, data packets, and retransmission packets);
- Due to overhearing listening from the radio environment

There are many proposed energy-based routing metrics, focusing on the following two approaches: (1) Minimizing total power consumption (The direction of power control) and (2) optimizing network lifetime. The network lifetime is the interval time from when the network starts operating until the first node is out of power. In other words, there is not enough power to send or receive packets.

1) Power control

The objective of this strategy is to minimize overall energy consumption. In that direction, Singh *et al.* [25] proposed the MTPR (Minimal Total Power Routing). Let e_l is the energy portion consumed to transmit or receive a packet on the link l. So, the total energy consumed to transmit a packet from the source node S to the destination node D on the route p can be determined as follows:

$$\mathrm{E_p} = \sum_{\mathrm{l \in p}} \mathrm{e_l} \quad (14)$$

This routing metric will prioritize routes that have shorter hops than the route has fewer hops, but the distance of each hop is longer. Although this solution is more efficient energy and less interference, it will cause bottlenecks due to traffic concentrated going to low-cost paths. To reduce the risk of bottlenecking due to traffic overload, Michail *et al*. [26] propose an energy weight with the number of empty channels of a node at the time of consideration. Of course, this metric only suitable for multi-channel operation systems.

2) Optimizing network lifetime

For the purpose of balancing energy consumption between nodes in the network, Sheu *et al*. [27] proposed a routing metric based on the remaining battery capacity of the node. The remaining battery capacity ratio of the node, R_{brc}, can be determined as follows:

$$R_{brc} = \frac{E_i}{E_{max}} = \frac{Battery\ remaining\ capacity}{Battery\ full\ capacity} \quad (15)$$

To limit energy-rich routes, but also contain the mobile node exhausted energy, Gupta and Das [28] propose the definition of three levels to determining the energy status of a node as the base for implementing routing, in Table I.

TABLE I: THREE LEVELS THE ENERGY STATUS OF A NODE

Level	Energy Zones	Status

1	$E_i < 10\%$	Danger Zone
2	$10\% \leq E_i < 20\%$	Warning Zone
3	$E_i \geq 20\%$	Normal Zone

E. MBCR Metric

To improve energy efficiency, Singh et al. [25] proposed a routing metric, called MBCR (Minimum Battery Cost Routing), which purpose to selected the richer energy routes. The authors define c_t^i, is the battery capacity of the n_i at time t. The energy cost function of node n_i can be determined, as follows:

$$f_i(c_t^i) = \frac{1}{c_t^i} \quad (16)$$

As the battery capacity remaining of the node is decreased, the cost function value of the node n_i will increases. Let R_j is the total cost on the route j has D nodes, we have:

$$R_j = \sum_{i=0}^{D_j-1} f_i(c_t^i) \quad (17)$$

To find the route with the highest remaining battery capacity, we need to select the route i with the cost function value is the smallest, $R_i = \min\{R_j | j \in A\}$, where A is the set of candidate routes from the source node to the destination node. By putting the battery capacity in the costing function, MBCR always finds the route with the highest remaining battery capacity. However, the limitation of MBCR is still using the route, which has the highest total battery capacity route but contains the exhausted node.

F. MMBCR Metric

To solve the limitations of the MBCR, in [25] proposed MMBCR (Minimal Maximum Battery Cost Routing) metric for purpose excludes the highest battery capacity route but containing the exhausted node. The MMBCR metric can be determined, as follows:

$$R_i = max_{i \in path_j} f_i(c_t^i) \quad (18)$$

where, like MBCR metric, the route i obtained by the equation, as follows:

$$R_i = \min\{R_j | j \in A\}. \quad (19)$$

This metric always tries to avoid routes containing the energy exhausted node. Therefore, the network lifetime can be improved. However, the MMBCR may not guarantee the choice the route, which has the minimum total transmission power. To solve this issue, the CMMBCR metric is proposed, specifically as follows.

G. CMMBCR Metric

In [29], Toh *et al*. proposed the CMMBCR (Conditional MMBCR) metric, merged from two metrics: MTPR and MMBCR, and added a concept called *Threshold* for the purpose of increasing each node lifetime and using the more efficient battery, as follows:

- If all of the nodes in the candidate routes of the source-destination pair have the remaining battery capacity is higher than *threshold* value, then, the route with the smallest transmission power will be selected.
- If the candidate route contains the node wich remaining battery capacity is lower than the *threshold* value, then, uses the MMBCR mechanism to select the route.

To effective evaluation the routing metrics based energy approach. In [30] Kim et al. performed simulate and compare performance between metrics: MTPR, MMBCR, and CMMBCR. The results show that in the high-density network environment, MTPR is more suitable due to lower total energy consumption. In contrast, in a low-density network environment, MMBCR performs better due to limited the network partition issue.

IV. Review of Recent Routing Protocols

To further clarify the direction of performance improvement research as well as the metrics and routing protocols proposed for MANETs in recent years. We performed a short survey of the proposed routing protocols for MANETs in the last eight years, from 2010-2017, published in the IEEE Xplore Digital Library database. We divide the routing protocols into four categories, based on the main goal when proposed, as follows: Overall Performance, QoS, Energy, and Security. Detailed results of the survey are showed in Table II.

Performing the analysis of the data in Table II, we have obtained some useful information about the research trends in the past time, as follows: Survey results show that about 38 routing protocols for MANETs have been proposed and published in the IEEE Xplore Digital Library database for the last eight years.

100% of the studies performed proposed new routing protocols and performance comparisons with a number of other routing protocols based on simulation software. The studies for purpose overall performance have the highest number of studies and account for around 40% of the total studies. More than 90% of performance evaluations are performed on traditional simulation software such as NS2, OPNET, Glomosim, Around 10% protocols are implemented in self-developed simulators. Around 85% of the studies evaluation efficient the protocol proposed by comparison with the standard routing protocols in MANETs. The two most popular routing protocols used to compared performance with the proposed protocol is AODV and DSR.

To evaluate the performance of proposed protocols, the studies focused on performance criteria such as packet delivery ratio (PDR), average throughput, average end-to-end delay, and routing overhead. Around 90% of the studies show two of the above four criteria. The two most popular criteria used in the studies were: packet delivery ratio and average end-to-end delay.

When considering the issue of routing metrics. The survey results in Table II show that over 80% of the proposed protocols use routing multi-metrics. The two most commonly used routing metrics are hop count and link quality.

Based on the results of the survey and analysis, we present some proposed research directions and open issues in the next section.

TABLE II: ROUTING PROTOCOLS FOR MANETS INDEXED IN IEEE XPLORE DIGITAL LIBRARY, 2010-2017

	Protocol	Metrics routing	Compare with	Delay	PDR	Energy	Overhead	Special
Performance Overall	LBRP [31]	Link Quality	AODV, DSR, ZRP	YES	YES	NO	YES	NO
	CA-AOMDV [32]	Hop Count	AOMDV	YES	YES	NO	YES	YES
	EDRP [33]	Link Quality	AODV, PGP	YES	YES	NO	YES	NO
	D-ODMRP[34]	Delay	ODMRP	NO	YES	NO	YES	NO
	3DLIS [35]	Information of Neighbors	MDART	YES	YES	NO	YES	YES
	OANTGPS [36]	Phenomenon	AODV, AOMDV, DSR, ANET	YES	YES	NO	NO	NO
	PSR [37]	Topology Information	OLSR, DSDV, DSR	YES	YES	NO	YES	NO
	IAR [38]	Signal-to-Interference Ratio	CLWPR, PIAR, SPIAR	YES	YES	NO	YES	YES
	DCFP [39]	Connectivity Factors	NCPR, AODV	YES	YES	YES	YES	NO
	TLRC [40]	The Street & Number of Vehicles	GyTAR, STAR	YES	YES	NO	NO	NO
	iCAR-II [41]	Location, Speed & Direction	GPSR, GSR, GyTAR	YES	YES	NO	YES	YES
	3MRP [42]	Distance, Trajectory, Density & Losses	GPSR and VIRTUS	YES	YES	NO	NO	YES
	ZoMo [43]	Location based GPS	CBDRP and Brave	YES	YES	NO	YES	YES
	CBLTR [44]	Location, Throughput	CBVANET, AODV-CV, CBDRP	YES	NO	YES	YES	YES
	RARP [45]	Connection Time, Hop count & Risk	Conventional	NO	YES	NO	NO	YES
QoS Aware	QOD [46]	Queue Length & Mobility	E-AODV, S-Multihop, Two-hop	YES	NO	NO	YES	NO
	EG-RAODV [47]	Link Reliable	AODV, PBR	YES	YES	NO	YES	YES
	MAODV-BB [48]	Hop-count	MAODV	YES	YES	NO	YES	YES
	BCMRP [49]	Residual Bandwidth of link	DCAR and other protocols	NO	YES	NO	YES	YES
	CLDBRP [50]	Channel Quality Information	A lot of scenarios	YES	YES	NO	NO	YES
	MQSPR [51]	Delay, Availability, and Load	AODV & GPSR	YES	YES	NO	YES	YES
	DMR [52]	Delay	ETT & EMAT	YES	YES	NO	NO	YES
Energy Aware	AEADMRA [53]	Energy	ADRA, AOMDV, DSR, EC-GRID	YES	YES	YES	YES	NO
	LAER [54]	Link Stability & Drain Rate	GPSR, E-GPSR, PERRA, and LAER	NO	YES	YES	YES	YES
	PDTMRP [55]	Hop-count & Power	MAODV, RMAODV, Parallel MNTMR	YES	YES	YES	YES	NO
	DEL-CMAC [56]	Location, Power Allocation	IEEE 802.11 DCF, CoopMAC	YES	NO	YES	NO	YES
	ERBA [57]	Link Reliable	AODV, ROMSGP	YES	YES	NO	NO	YES
	EPRDSR [58]	Power	DSR, MPTR	YES	YES	YES	NO	YES
	FF-AOMDV [59]	Hop-count, Energy and Location	AOMDV, AOMR-LM	YES	YES	YES	YES	YES
	OEFS [60]	Residual Energy	E-CHANET	NO	NO	YES	NO	YES
Security Aware	PRISM [61]	Hop-count	ALARM	NO	NO	NO	NO	YES
	ALARM [62]	Link State & Location	OLSR	NO	NO	NO	YES	YES
	LTB-AODV [63]	Hop-count	AODV	YES	YES	NO	YES	YES
	ALERT [64]	Location	AO2P, ALARM, GPSR	YES	YES	NO	NO	YES
	TEAP [65]	Hop-count	MASK	YES	YES	NO	YES	NO
	AASR [66]	Hop-count	AODV, ANODR,	YES	NO	NO	NO	YES
	SUPERMAN [67]	Link State	IPSec, SAODV and SOLSR	YES	NO	NO	YES	NO
	SCOTRES_DSR [68]	Energy, Topology and Channel-Health	A lot of protocols	YES	YES	NO	NO	YES

V. Discussion

In this work, we first presented the main factors affecting the performance of MANETs. In Section III, we summarized the development history of routing metrics with four main approaches: traffic, radio information, energy, and location and mobility. Clearly, routing metrics used by routing protocols in order to achieve different goals of MANET applications. Therefore, we conducted a survey on proposed routing protocols for MANETs in the last eight years, from 2010 to 2017. The main materials for our survey were papers published in the IEEE Xplore Digital Library. The findings and discussions were presented in Section IV.

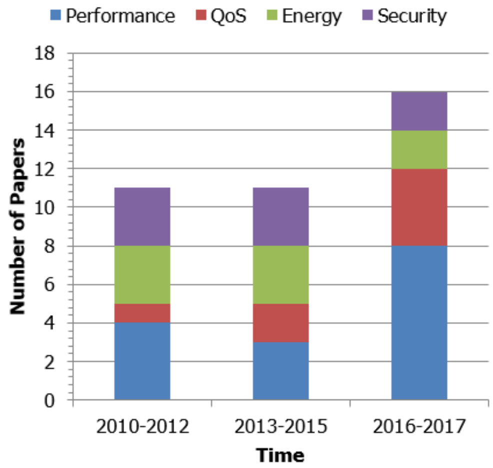

Fig. 5. The number of papers proposed routing protocols.

In each section, we discussed open issues as well as possible research directions. In all cases, we always considered the feasibility of proposed solutions to improve the efficiency of MANETs. As shown in Fig. 5, the number of papers that introduce new or modified routing protocols has been increasing over time and rapidly increasing over the recent two years (2016-2017). From the figure, we found that the proposals focusing on the overall network performance were always higher than others. In particular, the overall performance approached protocols reaches 40% of the total number of proposed protocols in the stage: 2016 – 2017. From our point of view, the context of 5G, with ultra-high frequency waves together with the extremely wide bandwidth and dense antenna systems will allow MANETs to improve throughput and end-to-end delay. However, the high density of base stations and equipment in 5G [8] also poses a significant challenge to the packet delivery capabilities of MANETs. The reason is that the environmental congestion and collision in the network tends to increase rapidly, in proportion to the density of devices in the network. Therefore, improving the network performance, quality of service and energy efficiency for MANETs will continue to be hot research topics in the future.

Clearly, routing metrics are designed for certain purposes in MANET applications. In Fig. 6, we present routing metrics used for the routing protocols surveyed. The numerical results show that most popular routing metrics used are: hop-count, link quality, location, and Energy. In addition, we can observe also the results showed in Table II to see that: recent studies tend to use multi-metrics, which are computed from different single metrics. In our view, to satisfy the complex quality of service conditions, this trend is necessary. Therefore, the issue concerning the selection of appropriate routing metrics will be an interesting research topic in the future.

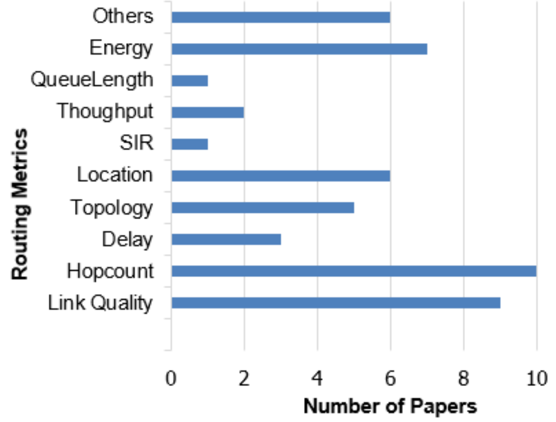

Fig. 6. Routing metrics used in the routing protocols surveyed.

Due to the limited capacity of mobile nodes, the problem of combining MANETs and other types of networks such as Cloud or Internet to create new network architectures is a necessary trend. This helps to bring unprecedented values to MANETs. Therefore, research on the cooperative mechanisms for Cloud-assisted MANETs or Internet-MANETs architecture will be interesting research topics. In traditional MANETs, the nodes are interconnected and based on peer-to-peer connections. However, in some MANET applications, the nodes may have very different roles and values. For example, in military MANETs, the network nodes having commanding roles always need to be protected and must have higher priority than other network nodes. Therefore, research to propose routing protocols for MANETs with special structures is necessary.

VI. Conclusion

Due to dynamic properties of MANETs, routing in these networks is considered a challenging problem. Survey of routing metrics and protocols will provide the necessary guidance to design of new routing protocols for MANETs. In the last decade, from 2010 up to now, there is a vast of routing metrics and protocols available for MANETs. In this work, we restricted our study to fundamental and popular ones. As our findings, routing metrics can be categorized into four types including traffic-based, radio information, energy, and location and mobility. The use of these metrics in routing will depend on the designed goals of each routing protocol. Thus, we examined routing protocols as well. Actually, we can divide MANET routing protocols into four groups according to their aims, that are: overall performance, quality of service, energy and security. Beside attempts to review and compare different routing protocols, we try to provide a whole view of the quick development in this research area during the last decade. As we discussed so far, there are many possible research directions that we can consider in future.

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