Research on Quality of Service Based Routing Protocols for Mobile Ad Hoc Networks

Selman Hizal* & Ahmet Zengin

Department of Computer Engineering, Sakarya University, Turkey
*E-mail: shizal@sakarya.edu.tr

Abstract. Quality of service (QoS) based routing protocols play a significant role in MANETs to maintain proper flow of data with efficient power consumption and without data loss. However, several network resource based technical challenges or issues are encountered in the design and implementation of QoS routing protocols that perform their routing function by considering the shortest route or the lowest cost. Furthermore, a secondary route is not reserved and alternative routes are not searched unless the established route is broken. The current structures of the state-of-the-art protocols for MANETs are not appropriate for today's high bandwidth and mobility requirements. Therefore, research on new routing protocols is needed, considering energy level, coverage, location, speed, movement, and link stability instead of only shortest path and lowest cost. This paper summarizes the main characteristics of QoS-based routing protocols to facilitate researchers to design and select QoS-based routing protocols. In this study, a wide range of protocols with their characteristics were classified according to QoS routing strategy, routing information update mechanism, interaction between network and MAC layer, QoS constraints, QoS guarantee type and number of discovered routes. In addition, the protocols were compared in terms of properties, design features, challenges and QoS metrics.

Keywords: *MANETs; protocol classification; protocol comparison; QoS; QoS-based routing.*

1 Introduction

Mobile ad-hoc networks (MANETs) are commonly used in military networks, emergency systems, rescue operation services, disaster management, and intelligent vehicular networks. A mobile node can join or leave the network spontaneously, acting as a specialized router by itself and making routing decisions based on the protocol strategy used. It is hard to keep a stable route from the source to the destination node due to the erratic network topology. Routing is one of the most important processes in mobile wireless communication networks. Routing is the process of calculating or selecting the way to communicate across the Internet from sender to destination [1]. Along the communication path, typically, there can be more than one intermediate node or router. Routing protocols can determine the best path for packet transmission using metrics such as bandwidth, delay, link reliability, cost, etc.

Received September 20th, 2020, Revised November 30th, 2020, Accepted for publication December 28th, 2020.
 ISSN: 2337-5787, DOI: 10.5614/itbj.ict.res.appl.2020.14.2.6

There are many different types of routing protocols based on the routing algorithm being used. Performance criteria, decision time or place, network information source, network information update, and timing are very important when designing a routing protocol [1]. Efficient routing may be obtained by supporting QoS requirements in MANETs. Throughput is the lowest common denominator requirement. Today's wide range of real-time multimedia applications greatly depend on guaranteed throughput. Other QoS metrics are requirements for timely delivering multimedia traffic, such as end-to-end performance, delay, and jitter. The main aim of QoS routing protocols is to discover a suitable path between the source and the destination node that guarantees the QoS requirements or constraints. Different perspectives on classification of QoS routing protocols have been used in the literature. Jabbar *et al.* [2] presented a survey on open issues in MANET routing. They classified various existing schemes of power-efficient routing. QoS routing protocols are generally categorized in the literature by their treatment of network topology, hierarchy, route discovery approach, location, or power awareness, interaction between network and MAC layer, and the number of supported QoS constraints. Although different studies evaluate QoS routing protocols from different perspectives, there is no study that considers all classification aspects. The current study presents a systematic approach to all these classifications and includes the number of paths discovered as a category in an integrated presentation.

The primary aim of this study was to provide a comprehensive and up-to-date comparison of QoS-based routing protocols for MANETs. This comparative study is meant to provide an advanced guide for researchers who are unacquainted with the breadth of issues pertaining to QoS-based routing protocols for MANETs. Compared with previously published studies, our comprehensive research on QoS-based routing protocols for MANETs offers several contributions, including:

1. The classification of QoS routing protocols into six categories and fourteen subcategories based on their underlying architectural framework. Comparative characteristics of QoS-based routing protocols were classified by their routing strategy, routing information update, the interaction between network and MAC layer, QoS metrics supported, types of QoS guarantees, and number of paths discovered. Thus, different characteristics and performance features of each protocol can be distinguished.
2. This research focused only on QoS-based routing protocols for MANETs. We evaluated typical research protocols involving similar approaches and the differences between these protocols.
3. Protocols that support single or multiple QoS metrics, such as battery power, bandwidth, link packet loss ratio, delay, jitter, throughput, link stability,

buffer fullness, maximum forward progress and minimum hop, were classified in this research.
4. The conclusion is hoped to inspire other researchers to do work on important and far-reaching topics related to QoS-based routing protocols for MANETs.

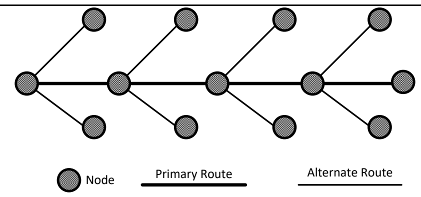
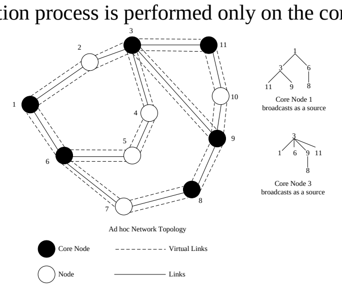
This paper is organized as follows: in Section 2 summarizes the main characteristics of QoS-based routing protocols for MANETs based on a review of the related literature. Also, challenges in QoS-based routing protocols are described and a taxonomy of QoS routing protocols by their corresponding features is given. In Section 3, a comprehensive overview of QoS-based routing protocols is presented, with a comparison table and each category is extensively discussed. In Section 4, the findings are summarized and potential areas of interest for future investigation are presented.

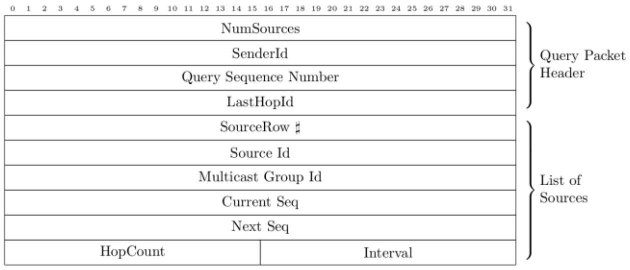
2 Classification of QoS-based Routing Protocols

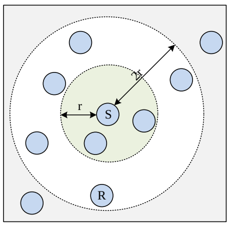
The most cited QoS-based routing protocols were selected for this research. A review of each protocol is given in alphabetical order in Table 1.

Table 1 QoS-based routing protocols for MANETs.

Routing Protocol	Description
AAQR [3]	The Application Aware QoS Routing Protocol (AAQR) uses QoS estimation and route discovery on demand to avoid generating extra overhead for QoS routing. Besides, it considers both delay and throughput requirements. Routes are discovered on demand and multimedia applications declare throughput and delay constraints before QoS routing. AAQR uses Floyd's algorithm [4] to calculate the shortest distance matrix of the minimum distance path delay between two hops. A disadvantage is the use of the Real Time Transport protocol (RTP) in AAQR, which limits the application areas for this protocol [3].
ACMP [5]	The Adaptive Core Based Multicast Routing Protocol (ACMP) looks for a compromise between data transmission effectiveness and routing message overhead by competently using power and bandwidth in MANETs. Group members are connected to each other on demand by using a group-shared tree structure. ACMP adaptively chooses the first source as the core node in a multicast session. Then it builds and protects the group-shared tree. Data transmission efficiency is ensured due to the tree structure. Also, routing message overhead is quite small. ACMP quickly detects link failure all along the data forwarding. Local route recovery sets up a temporary route during link loss. The optimal multicast tree is maintained by using periodical tree refreshing. ACMP sends a small number of message packets for the transmission of data packets between sender and receiver, thus using power and bandwidth efficiently [5].
ADQR [6]	The Adaptive Dispersity QoS Routing Protocol (ADQR) takes signal strength into account when deciding route selection. ADQR finds multiple disjoint paths on demand to support end-to-end QoS. The path that will probably live longest is preferred for transferring data. ADQR proposes a fast route maintenance scheme by monitoring changes in the network topology and performs rerouting before paths become inaccessible. ADQR significantly improves routing performance by using route discovery and maintenance mechanisms operating together [6].
AODV-BR [7]	The AODV Backup Routing protocol (AODV-BR) uses a combination of a primary route and alternative routes to form a network topology resembling a fish bone, as shown in Figure 1.

Routing Protocol	Description
	 **Figure 1** Network topology with the form of a fish bone [7]. The alternate routes can be triggered to continue data communication when the primary route is broken. The mesh is constructed without producing additional control messages and provides multiple alternate routes. AODV-BR produces more control packets and has longer end-to-end delay but increases the packet delivery ratio more than traditional AODV [8]. AODV-BR is not efficient under heavy traffic networks [7].
AODV-RD [9]	AODV-RD is an improved version of AODV-BR [7] that has a link failure and repairing mechanism in case the primary route is lost. It selects an alternate node that has stronger communicating power. Compared to AODV-BR [7], AODV-RD [9] has added a link prediction mechanism to reduce delay.
AQOR [10]	The Ad Hoc QoS On-Demand Routing Protocol (AQOR) is a reactive protocol and has a resource reservation mechanism for routing to support delay and bandwidth requirements in MANETs. AQOR propagates the route request and route reply message packets between nodes to obtain route discovery. AQOR uses a route sequence number that protects the routing loop and shows the newness of the control message packet. AQOR uses temporary reservation and destination triggered recovery together as QoS maintenance mechanism. AQOR responds rapidly to route failure and channel distortion. AQOR adjusts its admission policy with the offered load and mobility to keep the delivery rate above 95% [10].
BEQR [11]	The QoS-Aware Routing Protocol Based on Bandwidth Estimation (BEQR) uses control admission and feedback schemes as a hybrid to guarantee the QoS requirements of real-time multimedia applications. These two schemes support new data communication by using bandwidth estimation and distributing bandwidth information with 'hello' messages. BEQR only uses the bandwidth constraint and increases the packet delivery ratio. BEQR does not consider end-to-end throughput [11].
CEDAR [12]	The Core Extraction Distributed Ad Hoc Routing Protocol (CEDAR) selects a subset of nodes called the core of the network, as shown in Figure 2 [12]. Route request packets contain the source, destination and the requested bandwidth and are sent by the source node to the local core node, which is called the dominator. The dominator calculates and sets up a feasible QoS route. The dominator nodes use virtual links to exchange information by themselves. The route calculation process is performed only on the core path.  **Figure 2** Example of a core broadcast [12]. The core node only knows about the neighboring core node and has no information about the core subgraph in Figure 2. Thus, route maintenance and adaptation of topological changes are simplified. The route calculation process is performed when a specific request for a route is received. When a connection request is received, the core paths are organized. The process of

Routing Protocol	Description
	calculating the routes in CEDAR is robust. This is done at each core node, which reduces computation overhead in the network [12].
CQMP [10]	The Consolidated Query Packet Multicast Protocol with consolidated query packets (CQMP) is a strictly stated routing protocol that utilizes a kind of query packet forwarding mechanism when routing is demanded. A source node sends query packages to its neighbors and includes its ID and package sequence number. It also contains name lists of the source nodes, a query packet sequence number, last hop, and multicast group IDs, current and next sequence number as well as hop count, as shown in Figure 3 [13].  **Figure 3** Query packet format. The receiver takes several query packets coming from different source nodes. It compares the sender ID and the query sequence number with the cache that is present. If they match, it is treated as a duplicate and the packet is discarded. Otherwise it is processed and its ID, nextseq and interval values are saved in the receiver's routing table. The NumSources field is incremented every time. CQMP has less control overhead by consolidating the query packets. Since the data delivery ratio is reduced in high mobility conditions, CQMP is not efficient [13].
DSARP [14]	The Delay Sensitive Adaptive Routing Protocol (DSARP) is an on-demand protocol that is independent from the MAC layer. It has some additional features from dynamic source routing (DSR) [15], such as discovering a new path that is the shortest and guarantees the lowest average delay. DSARP outperforms the DSR protocol used in MANETs but has the following disadvantages: buffered packets must be rediscovered, which causes extra overhead. Also, DSARP is not feasible to guarantee end-to-end delay in unpredictable and frequently changing mobile node positions in MANETs [14].
EBR [16]	The Distributed Entropy-based Long-life QoS Routing Protocol (EBR) is a delay constraint that uses a new QoS metric, entropy (stability of a path), for selecting a long living path. The entropy metric helps to provide QoS requirements to MANETs. EBR is a location aware protocol and assumes that all nodes can acquire their position via GPS or any other positioning device. EBR determines the mobile ad hoc network's features with a location vector, a velocity vector and the signal range of each node. It has low message overhead and can obtain a high success ratio. It is suitable for rapidly changing ad hoc networks [16].
EHMRP [17]	The Efficient Hybrid Multicast Routing Protocol (EHMRP) is a source tree based multicast routing protocol. When a node wants to join the multicast tree it will broadcast the 'advertise' message to its neighboring nodes in a local group that are two hops removed from each other. Thus, each node will keep information on two hop nodes. If multiple packets are received it selects the one that is nearest and stable. If the source receives packets from nodes with the same distance, the node with the largest ID will be selected. If a node wants to join the cohort leader it sends a 'child' message, after which the cohort leader sends a 'leader' message to the node. If a source wants to leave the tree it will stop transmitting the 'child' message. The advantage of EHMRP is that it reduces control overhead, even when there are many nodes in the group, and provides packet delivery. Its disadvantage is link failure, which affects the delivery and the topology [17].
EMA-MPR [18]	The Energy and Mobility-Aware Multi-Point Relay Selection Mechanism for Multipath OLSRv2 (EMA-MPR) is a multipath, energy and mobility aware QoS-based routing protocol. It uses an improvement of the multi-point selection mechanism in the MP-OLSRv2 [19] protocol. Thus, the communication paths are more stable and the energy efficiency of the nodes is

Routing Protocol	Description
	increased. The selection of the MPR set for each node with one-hop neighbors depends on its availability, the degree of coverage and the willingness value, which can be predicted using the EMA-MPR mechanism. The willingness of the nodes in the EMA-MPR mechanism can have four values: high, default, low, and never [18]. EMA-MPR performs QoS-based routing by selecting the most stable nodes in terms of energy reserve and mobility to carry topological information to the environment. It increases route stability and link lifetime by providing QoS. Compared to MP-OLSRv2 [19], EMA-MPR provides significant improvements in packet delivery rate, average end-to-end latency and message overhead.
GAMAN [20]	The Genetic Algorithm-Based QoS Routing Protocol (GAMAN) finds the optimal route by considering the end-to-end delay and the transmission success ratio. GAMAN uses gene coding for encoding routes and collects genetic information on the links in each path. Using genetic algorithms for routing is effective but it is not feasible in terms of energy utilization and it increases overhead. GAMAN has better performance in small-sized MANET topologies in which the nodes have lower mobility. GAMAN is an example of how genetic algorithms may be applied to QoS-based routing protocols for MANETs [20].
HMCOP [21]	The Hybrid Multi-Constrained Optimal Path QoS Routing Protocol with Inaccurate Link State (HMCOP) uses a hybrid of a source algorithm and a distributed algorithm. HMCOP tries to decrease the protocol message overhead in the network and the computational complexity at the source node. It uses a reduced version of the Dijkstra algorithm [22] for finding k-shortest paths. The proposed algorithm contains a message-controlling scheme for admission control and a path optimization scheme. HMCOP works best on networks with 50 to 100 nodes [21].
HQMRP [23]	The Hierarchical QoS Multicast Routing Protocol (HQMRP) is an on-demand protocol based on a shared tree. It uses local information from each node that is a group member and information from other clusters. Thus, it is not necessary to maintain global state information. It uses multicast tree (MT) generation and MT update messages to maintain the multicast tree. Each node controls the links for delivering data with less delay and they set priority levels for the links without delay. HQMRP has delay reduction and removes unstable paths. It decreases message overhead on network but requires extra processing overhead in each local node [23].
IQRouting [24]	The Interference-aware QoS Routing Protocol (IQRouting) uses the throughput constraint. It considers the interference between links for making routing decisions. Bandwidth information is achieved by AODV's 'hello' message packets. IQRouting has low performance in terms of bandwidth consumption. An example of a mobile ad hoc network topology with sender and receiver nodes is shown in Figure 4. The receiver node is inside the carrier sense's range of sender nodes but not inside the transmission radius of any of the sender's neighbors. Therefore, the receiver node cannot inform the sender node of its channel usage and thus it cannot be subtracted from the sender's available channel capacity [24].  **Figure 4** The source node's transmission range (circle radius r) and its carrier-sense range (circle radius 2r) [24].
LGF [25]	The Location-Based Geocasting and Forwarding Routing Protocol (LGF) is an on-demand multicast protocol. It considers the geographic location of each node to make routing decisions. LGF algorithm splits the packets and transmits them to different intermediate nodes when a link is broken. It recovers link breakage by using the group members' hierarchical positions. Mobility of nodes changes the network topology. LGF is highly scalable even when there are frequent changes in topology. LGF has more processing overhead for large receiver groups. It also has more hierarchy and frequency of processing [25].

Routing Protocol	Description
LGT [26]	The Location Guided Tree Protocol (LGT) is an on-demand protocol that discovers the best route by considering the bandwidth and message overhead. LGT is feasible for mobile node positions that are nearest to each other. It maintains the geographical information of the nodes and does not need topological knowledge of the network. If nodes are far, LGT will determine network information such as topology, distance and hops. It uses the parameters *e* (wireless links) and *v* (number of mobile nodes). Group members only maintain local group information and have no knowledge about the network topology and the network distance. LGT reduces packet transmission cost by sending packets only to the nearest neighbor node in the group [26].
MBMA-OLSRv2 [27]	The Multipath Battery and Mobility Aware OLSRv2 (MBMA-OLSRv2) is an extension of RFC8218 [27]. MBMA-OLSRv2 is an extension of the authors' previous work MBQA-OLSRv2 [28]. It provides improvements by taking mobility into consideration and provides better performance in networks with dense mobile nodes [27].
MBQA-OLSRv2 [28]	Multi-criteria Based Multipath OLSR for Battery- and Queue-aware Routing in Multi-hop Ad hoc Wireless Networks (MBQA-OLSRv2) is an extension of RFC8218. It avoids traffic congestion and reduces energy consumption during routing and QoS in ad-hoc networks [28,29]. It selects the most efficient path by using the node battery power level, idle time, and queue length. It can increase the package delivery ratio better than other schemes. It also significantly reduces end-to-end latency, dead nodes, and energy cost per packet, especially in dense static networks.
MEQSA - OLSRv2 [30]	The Multicriteria-Based Hybrid Multipath Protocol for Energy-Efficient and QoS-Aware Data Routing in MANET-WSN Convergence Scenarios of IoT (MEQSA-OLSRv2) is a hybrid, multipath, energy- and QoS-aware routing protocol. It uses node rank level by considering QoS values such as node lifetime, residual battery energy, node idle time, node speed, and queue length. MEQSA-OLSRv2 reduces energy consumption and reduces energy cost per package by considering QoS parameters. Thus, it performs better than traditional protocols, even in networks with high mobility and traffic [30].
NSR [31]	The Node State Routing Protocol (NSR) is proactive protocol that stores serviceable state information of nodes such as IP address, packet queue size and battery power in a node routing table. NSR requires a GPS system for providing current node location, speed, and direction of movement. Thus, it avoids relying on link state propagation so only updating of the moving node state information is needed. NSR needs the accurate locations of the nodes and the node state updating mechanism is proactive, which leads to high overhead and poor network size scaling.
PLBQR [32]	The Predictive Location-Based QoS Routing Protocol (PLBQR) has a delay and location prediction scheme that can predict the location of nodes in the future. It can provide soft QoS guarantees and does not carry out resource reservation. It solves node migration problems and has low overhead. It is a robust routing protocol and specifies loop-free routes from sender to receiver nodes [32].
QMRPD [33]	The QoS Multicast Routing Protocol for Dynamic Group Topology (QMRPD) forms a multicast tree that fulfills multiple QoS requirements, i.e. packet loss, bandwidth, delay, and jitter. It develops a network model to make routing decisions and deals with multiple QoS constraints. A node can dynamically join or leave a multicast session without disrupting the multicast tree. QMRPD constructs a multicast tree with very low overhead. It searches multiple paths along the tree branches and selects the best one. QMRPD is a feasible approach for multicast routing with a dynamic group topology [33].
QOLSR [34]	The QoS Routing Protocol Using OLSR (QOLSR) protocol is an extension of the OLSR [35] protocol as specified in RFC3626, by including quality parameters such as delay and bandwidth. QOLSR is a table-driven protocol and finds the minimum-delay path with QOLSR1, QOLSR2 and QOLSR3. These three QoS-based variants of OLSR have been proposed for multipoint relay selection (see Figure 5) [34].

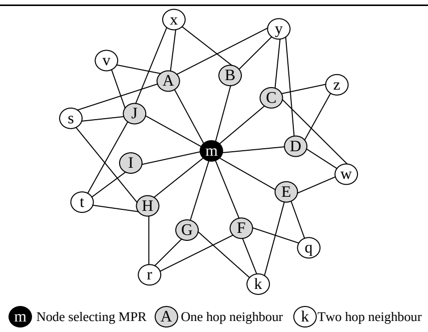


Figure 5 Example of multipoint relay selection [34].

Routing Protocol	Description
	Multipoint relaying is used to minimize the amount of identical retransmission while forwarding broadcast packets. This prevents a set of nodes from retransmitting a packet from all nodes to a subset of all nodes. QOLSR1 chooses the neighbor node with the maximum degree. If there are multiple neighbors with the maximum degree, the neighbor with the smallest delay is prioritized by QOLSR2. Otherwise priority is given to the neighbor node with the highest degree when there are multiple neighbors with the same minimum delay. QOLSR3 selects the node with the smallest delay between neighbors at a two-hop distance [34].
QS-AODV [36]	The Quality of Service for Ad Hoc On-Demand Distance Vector Routing Protocol (QS-AODV) is an on-demand protocol and a modification of AODV [8]. It considers QoS requirements of applications such as e-mail, file transfer, telephone, video on demand, and video conferencing. Although these applications have various requirements for loss, delay, jitter, and bandwidth, QS-AODV makes routing decisions by considering only the bandwidth metric. It has a local repair mechanism to initiate route discovery in the upstream of a broken link. QS-AODV has better performance in terms of the packet delivery ratio in heavy traffic with a slightly longer end-to-end delay.
RAODV [37]	The Reliable AODV Protocol (RAODV) is a security aware protocol that detects and avoids misbehaving nodes for supporting end-to-end QoS goodput. Its main objective is to detect and block misbehaving nodes that agree to send packets to other nodes but subsequently drop these packets. RAODV increases QoS performance and quality of cooperating nodes in mobile ad-hoc networks. It cannot detect misbehaving nodes when the node maintains the ratio between dropping and forwarding packets. RAODV achieves considerable goodput at different mobility rates (up to 25%) [37].
SQ-AODV [38]	The novel Energy-aware Stability-based Routing Protocol for Enhanced QoS in Wireless Ad-hoc Networks (SQ-AODV) is a dynamic routing protocol. It uses local node information without any additional control packet message. SQ-AODV brings the application, network, and physical layers together within a cross-layer architecture. It uses the energy drain rate at intermediate nodes for selecting a route. It has a mechanism for finding another feasible route before link breakage. Experiments based on simulations have shown that SQ-AODV can improve the packet delivery ratio compared to the traditional AODV protocol [8]. SQ-AODV decreases packet drop significantly and uses network sources effectively [38].
TBR [39]	Ticket-Based Probing Distributed Quality-of-Service Routing in Ad Hoc Networks (TBR) proposes a multipath distributed scheme without flooding and uses the throughput and delay constraints to minimize routing overhead. TBR assumes that the network topology does not change frequently and only supports soft QoS guarantees [39].
TDR [40]	The Trigger-Based Distributed QoS Routing in Mobile Ad Hoc (TDR) is an on-demand distributed routing protocol for supporting QoS requirements of multimedia applications. Although it has a rerouting mechanism with failure prediction before link breakage occurs, it sustains only one route in each session. It reduces overhead of control messages and provides better QoS compared with existing QoS aware routing protocols in MANETs [40].

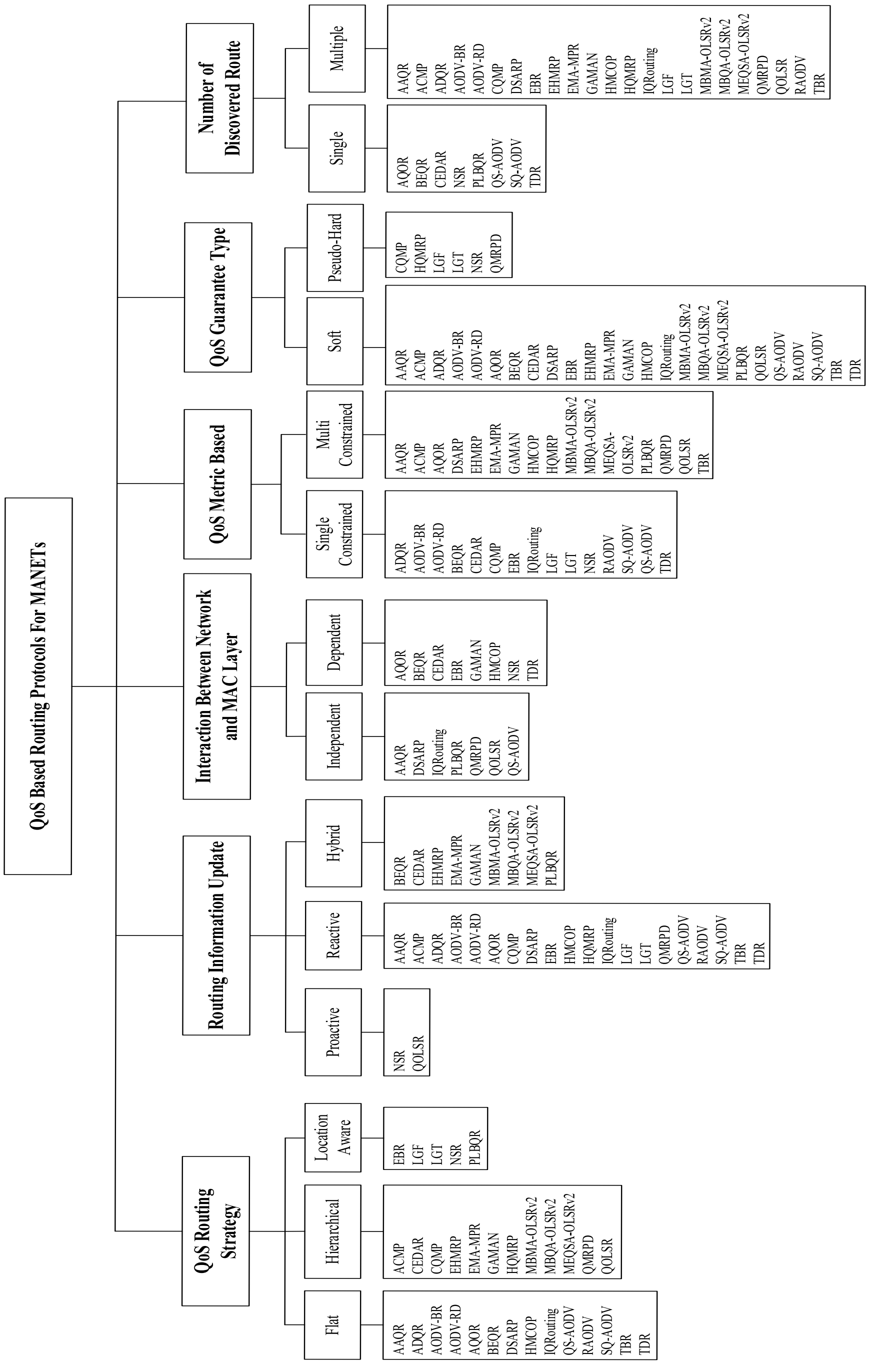


Figure 6 Taxonomy of QoS-based routing protocols for MANET.

QoS routing protocols can be classified according to their route discovery process (proactive, reactive, hybrid) and their network topology (flat, hierarchical, location-aware) used [2]. Another classification category is interaction between the MAC layer and the network [23]. On the other hand, QoS routing protocols can also be classified based on QoS metrics supported (single constrained, multi constrained) and QoS guarantee type (soft, hard). In this research, we additionally classified QoS routing protocols based on the number of discovered route (single, multiple).

To comprehend QoS routing protocols better it is important to use appropriate classification methods. These methods support researchers or designers to figure out distinct characteristics of QoS routing protocols. Therefore, we classified the discussed routing protocols into six categories and fourteen subcategories based on their underlying architectural framework, as shown in Figure 6.

2.1 QoS Routing Strategy

QoS-based routing protocols use their own routing strategy to evaluate which path will be the best for data communication between mobile nodes. These strategies vary depending on QoS performance criteria, QoS routing decision place, i.e. each node (distributed), central node (centralized), core node (hierarchical), and originating node (source). The current method of classifying QoS routing protocols is based on interaction between network members due to path construction and hierarchy. QoS routing strategies can be classified as flat, hierarchical or location aware. Although QoS routing protocols usually assume a flat network topology by considering network and mobile node resources, the power and computing capability are the same. However, this consideration may not be used in practice since there are different types of nodes with various functions, such as role, mobility, computing capacity and power. In Figure 6 (left), QoS routing protocols based on routing strategy are listed. The QoS routing protocols that are classified under the flat category are: AAQR [3], ADQR [6], AODV-BR [7], AODV-RD [9], AQOR [10], BEQR [11], DSARP [14], HMCOP [21], IQRouting [24], QS-AODV [36], RAODV [37], SQ-AODV [38], TBR [39], and TDR [40]. Nodes can be distributed in a hierarchical order in the network by using clustering techniques.

Hierarchy improves scalability of the network and reduces message overhead by giving group leadership to some nodes. According to network topology, QoS routing protocols classified under the hierarchical category are: ACMP [5], CEDAR [12], CQMP [13], EHMRP [17], GAMAN [20] HQMRP [23], QMRPD [33] and QOLSR [34]. Nodes can be location aware to retrieve location information of other nodes in the network. The most useful method for providing accurate location information of other nodes is to use GPS, Bluetooth or other location identification tools. This location information is used for determining routing paths. This type of network topology is classified by location aware routing protocols. These are: EBR [16], LGF [25], LGT [26], NSR [31] and PLBQR [32].

2.2 Routing Information Update

QoS-based ad-hoc routing protocols that include a routing information update scheme can be broadly classified as being proactive (table driven), reactive (on demand) and hybrid. In Figure 6 (left), the QoS routing protocols based on routing information update are listed. Each mobile node contains a routing table that is updated frequently. Whenever there is a change in the network topology, each node sends the changed information to the other nodes. The QoS routing protocols classified under the proactive category are NSR [31] and QOLSR [34]. Mobile nodes can discover and select a feasible route on demand. They send control message packets to other nodes to discover the entire network. This has the advantage of using less message overhead than proactive routing protocols. Hence, on-demand routing protocols are preferable in MANETs. However, some researchers think that reactive routing protocols are more suitable for MANETs [41].

On-demand QoS-based routing protocols are: AAQR [3], ACMP [5], ADQR [6], AODV-BR [7], AODV-RD [9], AQOR [10], CQMP [13], DSARP [14], EBR [16], HMCOP [21] HQMRP [23], IQRouting [24], LGF [25], LGT [26], QMRPD [33], QS-AODV [36], RAODV [37], SQ-AODV [38], TBR [39] and TDR [40]. A hybrid routing protocol is a combination of a proactive and a reactive protocol, taking the best features from each. There are various protocols in the literature that fall under the hybrid routing protocol category: BEQR [11], CEDAR [12], EHMRP [17], GAMAN [20] and PLBQR [32].

2.3 Interaction between Network and MAC Layer

Mobile nodes may be independent or dependent from the interaction between the network and the MAC layer for QoS provisioning. In Figure 6 (middle), the QoS-based routing protocols considering interaction between MAC layer and network layer are classified into two categories. AAQR [3], DSARP [14], IQRouting [24], PLBQR [32], QMRPD [33], QOLSR [34] and QS-AODV [36] are independent QoS routing protocols. Some protocols that support a routing protocol for QoS provisioning are dependent on the MAC layer. They perform resource reservation and guarantee QoS requirements. AQOR [10], BEQR [11], CEDAR [12], EBR [16], GAMAN [20], HMCOP [21], NSR [31] and TDR [40] are dependent QoS routing protocols.

2.4 QoS Constraint Based

QoS-based routing protocols support application needs and select the best route by using network resources efficiently. Some of the major QoS constraints are:

1. Battery power. This is an important factor in mobile communication in MANETs. Mobile nodes generally have a limited energy source. To communicate with other nodes, each of the nodes requires an amount of energy for both receiving and transmitting packets. The battery usage must be sufficient to support maximum packet delivery.
2. Link stability. This is the state of a link delivering signals without corruption, which guarantees signals to reach the desired destination. It is important to eliminate any issues that could cause packet loss during transmission, such as signal weakness and external environment factors.
3. Buffer fullness. Mobile nodes mostly have a limited interface to store received packets. Their buffer may become full if their application's bandwidth requirement is high. This leads to a reduction of the number of packets in the buffer.
4. Maximum forward progress. Each node acts as a router that can forward traffic in a MANET. Maximum forward progress can be reduced by distributed network topologies.
5. Minimum hop. Packet transmission flows hop-by-hop over intermediate nodes. To reduce the routing overhead, some QoS-based routing protocols consider selecting a QoS route with minimum hop.

Ad-hoc QoS routing protocols based on QoS metric(s) can be broadly classified as single-constrained or multi-constrained. In Figure 6 (right), the QoS routing protocols based on QoS metric(s) are classified. Throughput is assumed as the most used QoS requirement in MANETs. Although some QoS-based routing protocols consider only one metric and are successful, they do not always gain high performance. CEDAR [12] uses only one QoS metric, i.e. bandwidth, for routing. However, most multimedia applications require many QoS constraints, such as delay, jitter, link stability, buffer fullness, cost, and others. For this reason, studies are currently moving from designing single-constrained to multi-constrained routing. Mobility is a big challenge for multi-constrained protocols due to finding the best path with multiple constraints at the same time. Multi-constrained routing protocols are: AAQR [3], ACMP [5], AQOR [10], DSARP [14], EHMRP [17], GAMAN [20], HMCOP [21], HQMRP [23], PLBQR [32], QMRPD [33], QOLSR [34] and TBR [39].

Figure 7 provides a schematic representation of the relations between QoS metrics and QoS-based routing protocols. Protocols are connected to each QoS metric with a line. If a protocol has more than one constraint it relates to more lines. If a protocol is designed to consider two metrics but not simultaneously it is considered single-constrained and is represented twice.

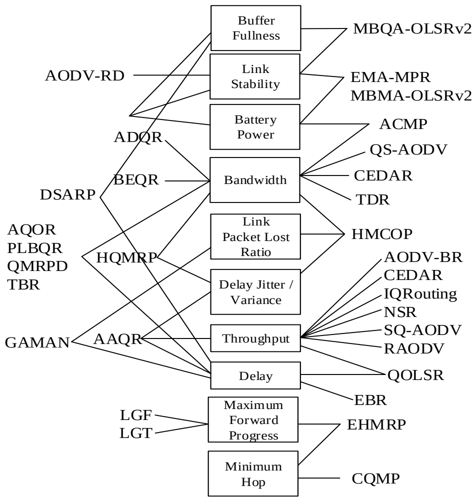


Figure 7 Relation between routing protocols and QoS metrics.

2.5 QoS Guarantee Type

Providing QoS guarantee type can generally be classified into hard/pseudo-hard QoS and soft QoS. In Figure 6 (right), QoS routing protocols based on QoS guarantee type are listed. If the QoS requirements are not guaranteed during the entire session it is called a soft QoS approach. Most protocols support soft QoS guarantees. AAQR [3], ACMP [5], ADQR [6], AODV-BR [7], AODV-RD [9], AQOR [10], BEQR [11], CEDAR [12], DSARP [14], EBR [16], EHMRP [17], GAMAN [20], HMCOP [21,27], IQRouting [24], PLBQR [32], QOLSR [34], QS-AODV [36], RAODV [37], SQ-AODV [38], TBR [39] and TDR [40] are examples of soft QoS routing protocols. If QoS requirements are guaranteed during the whole duration of the session, this is called a pseudo-hard QoS approach.

It is a challenging task to provide hard QoS guarantees to user applications in MANETs. Typical pseudo-hard QoS routing protocols are: CQMP [13], HQMRP [23], LGF [25], LGT [26], NSR [31] and QMRPD [33].

2.6 Number of Discovered Route

Mobility of the nodes often causes link breakage in MANETs. The remaining lifetime of links is used to determine whether the path is available or reliable before link breakage. Quality of service is supported by mechanisms that have been developed to estimate a link's lifetime. These mechanisms can discover or store alternative routes before link breakage occurs. It is hard to discover and establish the best path between two nodes in mobile ad-hoc networks by considering QoS requirements such as bandwidth, reliability, and link stability.

Ad-hoc QoS routing protocols based on the number of discovered routes can be broadly classified as being single or multiple. In Figure 6 (right), QoS routing protocols based on number of discovered routes are listed. Typical single route QoS routing protocols are: AQOR [10], BEQR [11], CEDAR [12], NSR [31], PLBQR [32], QS-AODV [36], SQ-AODV [38] and TDR [40]. Multiple route QoS routing protocols are: AAQR [3], ACMP [5], ADQR [6], AODV-BR [7], AODV-RD [9], CQMP [13], DSARP [14], EBR [16], EHMPR [17], GAMAN [20], HMCOP [21], HQMRP [23], IQRouting [24], LGF [25], LGT [26], QMRPD [33], QOLSR [34], RAODV [37] and TBR [39]. Storing secondary or more paths in the source node cache prevents congestion. The current load among neighbor nodes helps to calculate congestion. The advantages of storing multiple paths for the same destination in a routing table are high reliability and throughput but it requires more processing power and query packets [42].

3 Protocol Comparison and Evaluation

Distinguishing characteristics of QoS-based routing protocols are summarized in Figure 6 by routing strategy, routing information update, interaction between network and MAC layer, QoS metrics supported, QoS guarantee type, the number of discovered routes. Researchers may easily decide on characteristics to design new QoS-based routing protocols for MANETs by using the taxonomy in Figure 6. Researchers may consider the following recommendations depending on the comparisons in Tables 2 to 4. In Table 2, the flat routing protocols are compared according to four criteria. NDR indicates the number of paths being set from the source to the destination through other nodes. They also suggest alternative route paths if the primary link is broken. Route metric specifies which QoS metrics are considered, such as battery power, delay, throughput, link stability, bandwidth, etc. It is noticeable that AODV's different versions focus on a different single QoS metric.

Route maintenance is important as a mechanism for repairing links between the source and the destination before link breakage occurs. Communication links may be broken frequently because nodes can join or leave a MANET at any time, so always keeping a backup route will make a QoS routing protocol more reliable and powerful. It is important to have alternative routes in order to have more efficient routing and improve QoS performance. Communication overhead (CO) simply refers to the number of message packets sent during routing requests or setting paths. It is preferable to have a low CO to achieve the performance required in the network.

Table 2 Comparison of flat routing protocols .

Protocol	Number of Discovered Routes	Route Metric	Route Maintenance	Overhead
AODV-BR	Multi	Throughput	Alternate routes can be triggered to continue data communication when the primary route is broken	High
AODV-RD	Multi	Link Stability	Has link failure and repair mechanisms in case the primary route is lost	High
QS-AODV	Single	Bandwidth	Has a local repair mechanism to initiate route discovery in the upstream of a broken link	High
RAODV	Single	Throughput	Detects and avoids misbehaving nodes	High
SQ-AODV	Single	Throughput	Has a mechanism for finding another feasible route before link breakage	Medium

In Table 3 hierarchical routing protocols are compared. Hierarchical routing is an important strategy when managing a wide variety of devices in a network.

Table 3 Comparison of Hierarchical Routing Protocols

Protocol	Number of Discovered Routes	Routing Information Update	Route Metric	Route Maintenance	Overhead
ACMP	Multiple	Reactive	Battery Power, Bandwidth	Local route recovery	Low
CEDAR	Single	Hybrid	Bandwidth	Core nodes conduct route maintenance	Low
CQMP	Multiple	Reactive	Minimum Hop	Provides alternative paths	Medium
EHMRP	Multiple	Hybrid	Maximum Forward Progress, Minimum Hop	Alternate routes by mobility prediction using GPS	Medium
EMA-MPR	Multiple	Hybrid	Battery Power, Link Stability	There are backup routes in case of main route failure	Medium
GAMAN	Multiple	Hybrid	Packet Loss Ratio, Delay	Facilitates re-routing and route-repairing schemes	High
HQMRP	Multiple	Reactive	Bandwidth, Delay	Removes unstable paths and forwards through a stable path	High
MBMA-OLSRv2	Multiple	Hybrid	Mobility, Battery Power	Provides backup routes in case of route failure	Medium
MBQA-OLSRv2	Multiple	Hybrid	Energy, Queue Length	Uses the MP-OLSR route recovery process	Medium
MEQSA-OLSRv2	Multiple	Hybrid	Node Lifetime, Energy, Queue Length	Selects high reliability paths and stores them for a long time	Low
QMRPD	Multiple	Reactive	Delay, Jitter, Packet Loss, Bandwidth	If there are no feasible paths, a new path is computed	Low
QOLSR	Multiple	Proactive	Throughput, Delay	Calculates the optimal shortest paths with limited topology knowledge	Low

The MANET network topology is changed frequently, hence using a reactive (on-demand) approach is important. In hierarchical QoS-based routing protocols the number of discovered routes is either single or multiple. The route metrics considered during communication between nodes may also differ but generally it is more than one route metric. Although CEDAR developed only a single constraint (bandwidth) and achieved good results, researchers may have to devise new multi-constrained QoS routing protocols to meet QoS needs of multimedia applications. Route maintenance varies from protocol to protocol, but each one tries to find alternative paths before link failure occurs. In Table 4, location aware routing protocols are compared. MAC and network layer dependent protocols are more suitable for QoS performance than others. In topologies with high mobility it is more efficient to use a cross layer architecture and multiple QoS metrics [42,43]. It is difficult to maintain pseudo-hard QoS guarantees. However, a robust QoS routing protocol fulfills the needs during data transfer continuously.

Table 4 Comparison of location aware routing protocols.

Protocol	Number of Discovered Routes	Interaction between Network and MAC Layer	QoS Guarantee Type	Route Metric	Route Maintenance	Overhead
EBR	Multi	Dependent	Soft	Delay	Can make selection of a long-life route with minimum delay using entropy metrics	Low
LGF	Multi	N/A	Pseudo-hard	Maximum Forward Progress	Splits packets and transmits them to different intermediate nodes after a link is broken	High
LGT	Multi	N/A	Pseudo-hard	Maximum Forward Progress	N/A	Low
NSR	Single	Dependent	Pseudo-hard	Throughput	N/A	High
PLBQR	Single	Independent	Soft	Bandwidth, Delay	Can predict the location of a node in the future	Low

3.1 The Need to Develop New Protocols for MANETs

MANETs have several challenges, such as limited network resources, battery problems, dynamic topologies, and a variety of other technical challenges. Many QoS-based routing protocols have been implemented to address these issues.

Routing in MANETs is a very challenging process because the nodes in the network move randomly and they often have limited energy, computing and storage resources. In MANETs, traditional routing protocols perform routing by taking the shortest route or the lowest cost into the consideration. A secondary route is not reserved or alternative routes are not searched unless the used route is broken. Therefore, across increasing the size and complexity, new approaches are needed that consider additional constraints besides lowest cost and shortest path. There is a need for designing new routing protocols by considering the energy level, coverage, location, speed, movement, and link stability parameters for QoS constrained applications.

4 Conclusion and Future Directions

In this research, QoS-based routing protocols for MANETs were reviewed. Many different approaches were considered to cover important advances in the field. This study also classified each protocol according to its characteristics, presenting the protocols in terms of QoS routing strategy, routing information update mechanism, interaction between network and MAC layer, QoS metrics supported, QoS guarantee type and number of discovered routes. Although it is a very challenging task, designing QoS protocols for MANETs is quite an exciting research topic. It is highly expected that MANETs will have wide usage in the communication networks of the future.

Many researchers have studied important QoS-based routing protocol issues and challenges. However, there are still several issues deserving further investigation in QoS-based routing protocols for MANETs. Our main purpose in this work was to improve the AODV routing protocol to consider QoS metrics such as bandwidth, battery power, link stability, and delay. A specific routing maintenance algorithm with medium communication overhead will also be adopted. The new protocol will have collaboration of secure nodes and will support several QoS metrics.

References

[1] Yahaya, C., Abd Latiff, M.S. & Mohamed, A.B., *A Review of Routing Strategies for Optical Burst Switched Networks*, Int. J. Commun. Syst., **26**(3), pp. 315-336, Mar. 2013. DOI: 10.1002/dac.1345.

[2] Jabbar, W.A., Ismail, M., Nordin, R. & Arif, S., *Power-Efficient Routing Schemes for Manets: A Survey and Open Issues*, Wirel. Networks, **23**(6), pp. 1917-1952, Aug. 2017. DOI: 10.1007/s11276-016-1263-6.

[3] Li, D., Liu, Y., Zeng, P. & Yu, H., *Advances in Computational Science,* Engineering and Information Technology, **225**(1). Heidelberg: Springer International Publishing, 2013.

[4] Floyd, R.W., *Algorithm 97: Shortest Path*, Commun. ACM, **5**(6), p. 345, Jun. 1962. DOI: 10.1145/367766.368168.

[5] Junhai, L., Danxia, Y., Liu, X. & Mingyu, F., *A Survey of Multicast Routing Protocols for Mobile Ad-Hoc Networks*, IEEE Commun. Surv. Tutorials, **11**(1), pp. 78-91, 2009. DOI: 10.1109/SURV.2009.090107.

[6] Chen, L. & Heinzelman, W., *A Survey of Routing Protocols that Support QoS in Mobile Ad Hoc Networks*, IEEE Netw., **21**(6), pp. 30-38, 2007. DOI: 10.1109/MNET.2007.4395108.

[7] Bosunia, M.R., Jeong, D.P., Park, C. & Jeong, S.H., *A New Routing Protocol with High Energy Efficiency and Reliability for Data Delivery in Mobile Ad Hoc Networks*, Int. J. Distrib. Sens. Networks, 2015, pp. 1-8, 2015. DOI: 10.1155/2015/716436.

[8] Perkins, C., Belding-Royer, E. & Das, S., *Ad hoc On-demand Distance Vector (AODV) Routing, Internet RFCs*, **285**, pp. 1-38, 2003. DOI: 10.1074/jbc.R109.041087.

[9] Liu, J. & Li, F., *An Improvement of AODV Protocol Based on Reliable Delivery in Mobile Ad Hoc Networks*, in 2009 Fifth International Conference on Information Assurance and Security, **1**, pp. 507-510, 2009. DOI: 10.1109/IAS.2009.78.

[10] Boukerche, A., Turgut, B., Aydin, N., Ahmad, M.Z., Bölöni, L. & Turgut, D., *Routing Protocols in Ad Hoc Networks: A Survey*, Comput. Networks, **55**(13), pp. 3032-3080, Sep. 2011. DOI: 10.1016/j.comnet.2011.05.010.

[11] Su, Y.W. & Tzeng, S.S., *QoS Routing Protocol with Multiple Node-Disjoint Paths in Ad Hoc Networks*, Wirel. Pers. Commun., **83**(3), pp. 1867-1885, Aug. 2015. DOI: 10.1007/s11277-015-2486-z.

[12] Hosek, J., Kovac, D., Vajsar, P. & Potfay, A., *QoS Support in Routing Protocols for MANET*, in 2013 3^{6th} International Conference on Telecommunications and Signal Processing (TSP), pp. 118-122, , Jul. 2013. DOI: 10.1109/TSP.2013.6613903.

[13] Bitam, S. & Mellouk, A., *MQBM: an Autonomic Qos Multicast Routing Protocol for Mobile Ad Hoc Networks*, in 2012 IEEE International Conference on Communications (ICC), pp. 5488-5492, , Jun. 2012. DOI: 10.1109/ICC.2012.6364438.

[14] Wang, N.C., *Power-Aware Dual-Tree-Based Multicast Routing Protocol for Mobile Ad Hoc Networks*, IET Commun., **6**(7), p. 724, 2012, DOI: 10.1049/iet-com.2011.0073.

[15] Johnson, D.B. & Maltz, D.A., *Mobile Computing*, 353, Boston, MA: Springer US, 1996.

[16] Lavanya, P., Reddy, V.S.K. & Prasad, A.M., *Research and Survey on Multicast Routing Protocols for MANETs*, in 2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp. 1-4, , Feb. 2017. DOI: 10.1109/ICECCT.2017.8117929.

[17] Walikar, G.A. & Biradar, R.C., *A Survey on Hybrid Routing Mechanisms in Mobile Ad Hoc Networks*, J. Netw. Comput. Appl., **77**, pp. 48-63, Jan. 2017. DOI: 10.1016/j.jnca.2016.10.014.

[18] Jabbar, W.A., Ismail, M., Nordin, R. & Ramli, R.M., *EMA-MPR: Energy and Mobility-Aware Multi-Point Relay Selection Mechanism for Multipath Olsrv2*, in 2017 IEEE 13th Malaysia International Conference on Communications (MICC), pp. 1-6, , Nov. 2017. DOI: 10.1109/MICC. 2017.8311721.

[19] Yi, J. & Parrein, B., *RFC 8218 – Multipath Extension for the Optimized Link State Routing Protocol Version 2 (OLSRv2)*, Internet Eng. Task Force, 2017.

[20] Maniscalco, V., Polito, S.G. & Gentile, L., *GA Application with Hybrid Encoding for QoS Routing*, in AIP Conference Proceedings, 1648, p. 780007, 2015. DOI: 10.1063/1.4912987.

[21] Sanguankotchakorn, T. & Perera, N., *Hybrid Multi-constrained Optimal Path QoS Routing with Inaccurate Link State*, in 2010 Ninth International Conference on Networks, pp. 321-326, 2010. DOI: 10.1109/ ICN.2010.57.

[22] AbuSalim, S.W G., Ibrahim, R., Zainuri Saringat, M., Jamel, S. & Abdul Wahab, J., *Comparative Analysis between Dijkstra and Bellman-Ford Algorithms in Shortest Path Optimization*, IOP Conf. Ser. Mater. Sci. Eng., **917**, p. 012077, Sep. 2020. DOI: 10.1088/1757-899X/917/1/012077.

[23] Qabajeh, M.M., Abdalla, A.H., Khalifa, O.O. & Qabajeh, L.K., *A Survey on Scalable Multicasting in Mobile Ad Hoc Networks*, Wirel. Pers. Commun., **80**(1), pp. 369-393, Jan. 2015. DOI: 10.1007/s11277-014-2016-4.

[24] Thenmozhi, *An Effective Contention Aware Stable Path Finding Approach to Provide Quality of Service in Mobile Ad hoc Networks*, J. Comput. Sci., **7**(3), pp. 352-358, Mar. 2011. DOI: 10.3844/jcssp.2011.352.358.

[25] Gnanambigai, J. & Rengarajan, N., *A Novel Approach to Enhance the Network Lifetime for Hybrid Routing Protocol*, Int. J. Inf. Comput. Secur., **8**(2), p. 95, 2016. DOI: 10.1504/IJICS.2016.078117.

[26] Chen, K. & Nahrstedt, K., *Effective Location-Guided Tree Construction Algorithms for Small Group Multicast In MANET*, in Proceedings.Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies, **3**(1), pp. 1180-1189, 2002. DOI: 10.1109/INFCOM. 2002.1019368.

[27] Jabbar, W.A., *Mobility-based Performance Comparison of MBQA-OLSRv2 and MBMA-OLSRv2 Routing Protocols*, in 2019 23rd International Computer Science and Engineering Conference (ICSEC), Oct. 2019, pp. 281-286, 2019. DOI: 10.1109/ICSEC47112.2019.8974771.

[28] Jabbar, W.A., Ismail, M. & Nordin, R., *Multi-Criteria Based Multipath OLSR for Battery and Queue-Aware Routing in Multi-Hop Ad Hoc Wireless Networks*, Wirel. Networks, **21**(4), pp. 1309-1326, May 2015. DOI: 10.1007/s11276-014-0857-0.

[29] Jabbar, W.A., Ismai, M., Nordin, R. & Ramli, R.M., *Traffic Load-Based Analysis of MBQA-OLSR Routing Protocol in Wireless Ad Hoc Networks*,

in TENCON 2017 – 2017 IEEE Region 10 Conference, pp. 2677-2682, , Nov. 2017. DOI: 10.1109/TENCON.2017.8228315.

[30] Jabbar, W.A., Saad, W.K. & Ismail, M., *MEQSA-OLSRv2: A Multicriteria-Based Hybrid Multipath Protocol for Energy-Efficient and QoS-Aware Data Routing*, in MANET-WSN Convergence Scenarios of IoT, IEEE Access, **6**, pp. 76546-76572, 2018. DOI: 10.1109/ACCESS. 2018.2882853.

[31] Maleki, H., Kargahi, M. & Jabbehdari, S., *RTLB-DSR: A Load-Balancing DSR Based QoS Routing Protocol in MANETs*, in 2014 4th International Conference on Computer and Knowledge Engineering (ICCKE), pp. 728-735, , Oct. 2014. DOI: 10.1109/ICCKE.2014.6993411.

[32] Sundar, S., Kumar, R., Harish, K. & Shanmugasundaram, M., *Manet Routing Protocols with Qos Support - A Survey*, Int. J. Eng. Technol., **5**(3), pp. 2077-2082, 2013.

[33] Kim, M., Choo, H., Mutka, M.W., Lim, H.J. & Park, K., *On QoS Multicast Routing Algorithms Using K-Minimum Steiner Trees*, Inf. Sci. (Ny)., **238**, pp. 190-204, Jul. 2013. DOI: 10.1016/j.ins.2013.03.006.

[34] Munaretto, A. & Fonseca, M., *Routing and Quality of Service Support for Mobile Ad Hoc Networks*, Comput. Networks, **51**(11), pp. 3142-3156, Aug. 2007. DOI: 10.1016/j.comnet.2006.12.010.

[35] Clausen, T. & Jacquet, P., *RFC 3626 - Optimized Link State Routing Protocol (OLSR)*, IETF RFC3626, p. 75, 2003.

[36] Yihai Zhang & Gulliver, T.A., *Quality of Service for Ad Hoc On-Demand Distance Vector Routing*, in WiMob'2005, IEEE International Conference on Wireless And Mobile Computing, Networking And Communications, **3**, pp. 192-196, 2005. DOI: 10.1109/WIMOB.2005.1512903.

[37] Perti, A. & Sharma, P., *Reliable AODV Protocol for Wireless Ad Hoc Networking*, in 2009 IEEE International Advance Computing Conference, **00**(March), pp. 675-680, 2009. DOI: 10.1109/IADCC.2009.4809093.

[38] Veerayya, M., Sharma, V. & Karandikar, A., *SQ-AODV: A Novel Energy-Aware Stability-Based Routing Protocol for Enhanced Qos in Wireless Ad-Hoc Networks*, in MILCOM 2008 - 2008 IEEE Military Communications Conference, pp. 1-7, 2008. DOI: 10.1109/ MILCOM.2008.4753608.

[39] Moussaoui, A. & Boukeream, A., *A Survey of Routing Protocols Based on Link-Stability in Mobile Ad Hoc Networks*, J. Netw. Comput. Appl., **47**, pp. 1-10, Jan. 2015. DOI: 10.1016/j.jnca.2014.09.007.

[40] Naik, L.L., Khan, R.U. & Mishra, R.B., *MANETs: QoS and Investigations on Optimized Link State Routing Protocol*, Int. J. Comput. Netw. Inf. Secur., **10**(10), pp. 26-37, Oct. 2018. DOI: 10.5815/ijcnis.2018.10.04.

[41] Alexiou, A., Bouras, C. & Papazois, A., *A Study of Forward Error Correction for Mobile Multicast*, Int. J. Commun. Syst., **24**(5), pp. 607-627, May 2011. DOI: 10.1002/dac.1178.

[42] Sridhar, S. & Baskaran, R., *Efficient routing in Mobile Adhoc networks Emphasizing Quality of Service by Trust & Energy Based AODV*, J. Commun. Softw. Syst., **11**(1), pp.1-7, 2015.

[43] Menaka, S. & Jayanthi, M.K., *Adaptive and Self Healing Routing for Mobile Ad Hoc Networks Using Cross Layer Design*, J. Comput. Inf. Technol. - CIT, **4**, pp.227-236, 2014. DOI: 102498/cit.1002407.