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Challenges and Advances in QoS Routing Protocols for Mobile Ad Hoc Networks

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Abstract— A Mobile Ad Hoc Network (MANET) is a collection of mobile nodes, which dynamically form a temporary network, without using any infrastructure like wireless access points or base-stations. The provision of QoS guarantees is much more challenging in Mobile Ad hoc Networks. There are many interesting applications such as multimedia services, disaster recovery etc can be supported if Quality-of-Service (QoS) support can be provided for MANETs. But QoS provisioning in MANETs is a very challenging problem when compared to wired IP networks. This is because of unpredictable node mobility, wireless multi-hop communication, contention for wireless channel access, limited battery power and range of mobile devices as well as the absence of a central coordination authority. So, the design of an efficient and reliable routing scheme providing QoS support for such applications is a difficult task. In this paper we studied the challenges and approaches for QoS aware routing techniques.

Keywords— Mobile Ad Hoc Network, Routing Protocols, Quality of Service, QoS Routing.

I. Introduction

Mobile Ad Hoc Networks (MANETs) are self-organizing, rapidly deployable and with no fixed infrastructure [1–3]. They are composed of wireless mobile nodes that can be deployed anywhere, and cooperate to dynamically establish communications using limited network management and administration [4]. Nodes in an ad hoc network may be highly mobile, or stationary, and may vary widely in terms of their capabilities and uses [4,5]. It is hoped that in the future, ad hoc networks will emerge as an effective complement to wired or wireless LANs, and even to wide-area mobile networking services, such as Personal Communication Systems (PCS). The successful implementation of mobile ad hoc networking technology presents a unique set of challenges, which differ from traditional wireless systems. These include effective multi-hop routing, MAC, mobility and data management, congestion control.

One of the most important aspects of the communications process is the design of the routing protocols used to establish and maintain multi-hop routes to allow the communication of data between nodes. As the MANETs are dynamic in nature, designing protocols for these networks is a challenging process. A considerable amount of research has been done in this area, and many multi-hop routing protocols have been developed. Most of these routing protocols build and rely on a uni-path route for each data transmission. The protocols are classified into two categories: table-driven, on-demand. While these protocols might be sufficient for a certain class of MANET applications, but are not adequate for the support of more demanding applications such as multimedia audio and video. Such applications require the network to provide guarantees on the QoS. This is achieved by using some mechanism such as QoS routing to find the best route which satisfies these requirements in the best way. QoS routing appears to be a solution to handle these problems. QoS routing requires not only finding a route from a source to a destination, but a route that satisfies the end-to-end QoS requirement, often given in terms of bandwidth, delay or loss probability. Quality of service is more difficult to achieve in ad hoc networks than in wired networks.

According to [6], QoS is a set of service requirements to be met by the network while transporting a flow. A flow is a packet stream from a source to a destination with an associated QoS. A fundamental requirement of any QoS mechanism is a measurable performance metric. Typical QoS metrics include *available bandwidth*, *packet loss rate*, *estimated delay*, *packet jitter*, *hop count* and *path reliability*. The key issue in providing QoS guarantees is how to determine paths that satisfy QoS constraints and solving this problem is referred as QoS aware routing.

This paper is organized as follows. The next section we have discussed how routing happens in MANETs. The challenges for provisioning QoS for MANETs are discussed in the section III. In section IV we have listed some of the important routing protocols which provide QoS. We draw the conclusions of our findings in the field of QoS routing in section V.

II. Routing in MANETs

Routing is the process of *discovery*, *selecting*, and *maintaining paths* from a source node to destination node to deliver data packets [7]. The goal of every routing algorithm is to direct traffic from source to destination, maximizing network performance whilst minimizing costs. In mobile ad hoc networks, routes are mainly multi hop due to limited propagation range, frequent topology changes since each network host moves randomly. Therefore, routing is an integral part of ad

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hoc communications. Routing is to find and maintain routes between nodes in a dynamic topology with possibly uni-directional links, using minimum resources.

According to [8], unlike wired networks or cellular networks, no central administration and no physical backbone infrastructure is installed in ad hoc networks. Every host can move to any direction at any speed and any time. Communication is achieved either through a single-hop if the communication nodes are close enough, or through relaying by intermediate nodes otherwise. If two hosts are not located in each other‘s transmission range, intermediate hosts will act as routers to build communication paths. This is the multi-hop characteristic of the ad hoc wireless network. Wireless mobiles are usually light-weight and battery-powered. Compared with wired lines, wireless links have much less available bandwidth. The features viz., dynamic topology, multi-hop communication, wireless interference, frequent connectivity changes and strict resource limitation make routing as a challenging problem in ad hoc wireless network.

A routing protocol for ad hoc wireless networks should have the following characteristics [9]:

1) It must be fully distributed.
2) It must be adaptive to frequent topology changes caused by the mobility of nodes.
3) Route computation and maintenance must involve a minimum number of nodes.
4) It must be loop-free and free from stale routes.
5) The number of packet collision must be kept to a minimum by limiting the number of broadcasts made by each node.
6) It must optimally use scarce resources such as bandwidth, computing power, memory and battery power.
7) It should be able to provide a certain level of QoS as demanded by the applications, and should also offer support for time-sensitive traffic.

Routing strategy and network structure are mainly used to classify routing protocols of MANETs [10,11]. According to the routing strategy the routing protocols can be categorized as *Table-driven* and *Source Initiated*, while depending on the network structure these are classified as *Flat Routing, Hierarchical Routing* and *Geographic Position Assisted Routing.* As shown in the Fig. 1 the Flat routing protocols are divided as Table-driven and Source Initiated protocols.

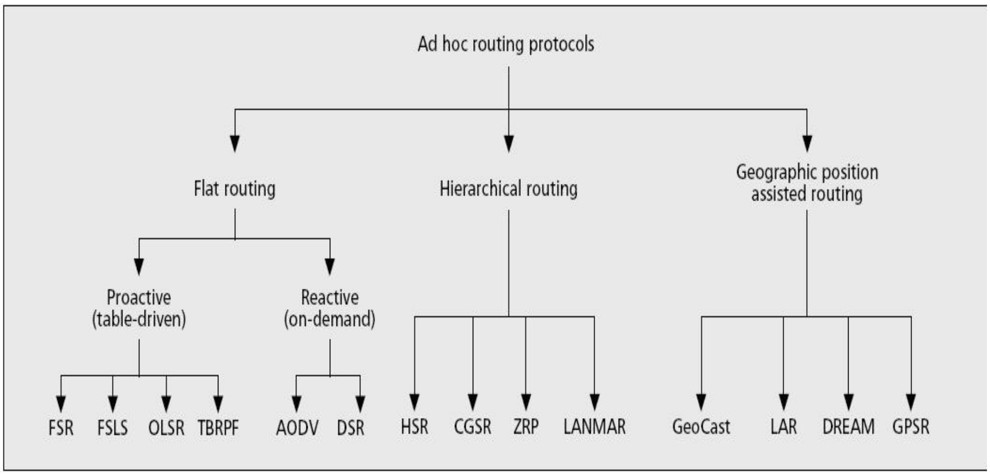

Fig. 1 Classification of Routing Protocols in MANETs

A. Table-driven or Proactive Protocols:

Proactive routing protocols attempt to maintain consistent, up-to-date routing information between every pair of nodes in the network by propagating, proactively, route updates at fixed intervals. Each and every node in the network maintains routing information to every other node in the network. Routing information is maintained in the routing tables and is often updated when there is a change in the network topology. The proactive protocols are not suitable for larger networks, as they need to maintain node entries for each and every node in the routing table of every node. These protocols include: Destination-Sequenced Distance- Vector (DSDV) routing, Clustered Gateway Switch Routing (CGSR), Wireless Routing Protocol (WRP), Optimized Link State Routing (OLSR) and Fisheye State Routing (FSR).

B. On-demand or Reactive Protocols

Reactive protocols, unlike table-driven ones, establish a route to a destination when there is a demand for it, usually initiated by the source node through discovery process within the network [12]. If a node wants to send a packet to another node then these protocols searches for the route in an on-demand manner and establishes the connection in order to transmit and receive the packets. The route discovery usually occurs by flooding the route request packets throughout the network. These protocols try to eliminate the conventional routing tables and consequently reduce the need for updating these tables to track changes in the network topology. Reactive routing protocols include: Dynamic Source Routing (DSR), Ad hoc On Demand Distance Vector (AODV) routing, Temporally Ordered Routing Algorithm (TORA) and Associativity Based Routing (ABR).

C. Hybrid Routing Protocols

Hybrid routing protocols are a new generation of protocol, which are both proactive and reactive in nature. These protocols are designed to increase scalability by allowing nodes with close proximity to work together to form some sort of a backbone to reduce the route discovery overheads. Purely proactive or purely reactive protocols perform well in a

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limited region of network setting. Most hybrid protocols proposed to date are zone-based, which means that the network is partitioned or seen as a number of zones by each node. Whereas other protocols group nodes into trees or clusters. Representative hybrid routing protocols include: Zone Routing Protocol (ZRP), Zone-based Hierarchal Link State routing protocol (ZHLS), Distributed Dynamic Routing (DDR) and Distributed spanning Trees based routing Protocol (DST)**.**

III. Challenges for Quality of Service (QoS) provisioning in MANETs

A network is expected to guarantee a set of measurable pre-specified service attributes to the users in terms of end-to-end performance such as delay, bandwidth, probability of packet loss, delay variance (jitter), processing power, buffer space etc. The goal of QoS provisioning is to achieve a more deterministic network behavior so that information carried by the network can be better delivered and network resources can be better utilized [13]. QoS provisioning in MANETs is very important in order to support real-time communications such as audio and video. But, provisioning of QoS over wireless networks is far more challenging than for wired networks because of variability of wireless links, node mobility, and lack of central coordination authority for QoS and channel assignment, limited battery power, multi hop communication and contention for accessing the wireless channel. Quality of service [14] sometimes refers to the level of quality of service, i.e. the guaranteed service quality.

A. QoS Model

QoS model specifies an architecture in which some kind of services could be provided in MANETs. The model includes QoS resources reservation signaling, QoS routing and QoS Medium Access Control (MAC) as shown in Fig 2.

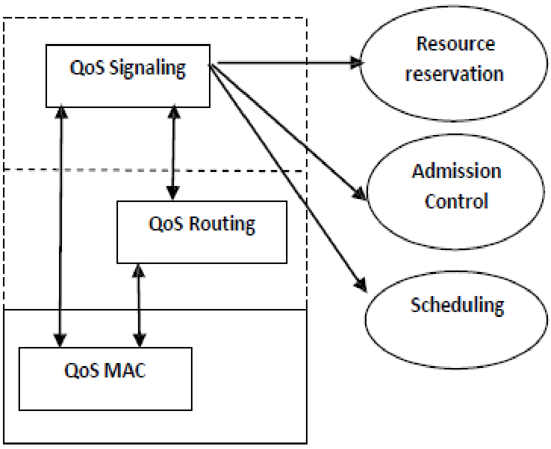

Fig. 2 QoS Model

The main requirements for a QoS Model for MANETs are as follows:-

Minimal overhead –The wireless link capacity, battery and computational resources in a wireless multi-hop network are quite limited. Therefore a QoS model for wireless multi-hop networks should minimize the signaling overhead as well as the computational overhead entailed in provisioning of QoS.

Robustness – QoS models should be capable of handling frequent route failures and dynamically changing network. The QoS model should have mechanisms to adapt to the changing topology without creating bottlenecks, in a fast and efficient manner.

Fairness – The QoS resources should be shared in a fair manner among the wireless clients, and misbehaving nodes should not be allowed to make use of the network's resources without relaying packets for other nodes. A fundamental requirement of any QoS mechanism is a measurable performance metric. Typical QoS metrics include *available bandwidth, packet loss rate, estimated delay, packet jitter, hop count and path reliability*.

The existing QoS models can be classified into two types based on their *fundamental operations – Integrated Service (IntServ)* and *Differentiated Services (DiffServ)* [15]. *IntServ* is a fine grained approach which provides QoS to individual flows. It uses Resource Reservation Protocol (RSVP) to provide a circuit switched service in packet switched network. It aims to emulate a connection-oriented, virtual circuit connection for each flow admitted to the network. IntServ provides Admission control. One of the main responsibilities of admission control is that the interference caused by adding a new flow should not make QoS of old flows get poorer than required. The drawback of IntServ is the scalability problem caused by the need of storing every flow state in the routes. *DiffServ* provides QoS to large class of data or aggregated traffic. It is a coarse grained approach. It maps flows into a set of service levels. Under the DiffServ model, an application does not explicitly signal the network (i.e. the routers) before transmitting data. Instead, the network tries to deliver a particular kind of service based on the QoS specified by each packet. In DiffServ, routers are divided into two types: *edge routers* and *core routers*. Edge routers are at the boundary of the networks. Core routers forward packets based on the Type of Service field and they also need to follow the Per-Hop-Behavior (PHB) which takes charge of scheduling of packets [16]. IntServ and DiffServ were proposed for static networks and thus cannot be applied directly to the mobile ad hoc environment. A QoS model designed for ad hoc networks must consider the unique features and challenges associated with mobile ad hoc networks. A Flexible QoS Model for MANETs (FQMM) considers the characteristics of MANETs and combines the high quality QoS of IntServ and service differentiation of DiffServ. The features of FQMM include: dynamic roles of nodes, hybrid provisioning and adaptive conditioning [17].

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B. QoS Parameters

These differ from application to application. Incase of multimedia applications, the data rate and delay are the key factors, whereas, in military use, security and reliability become more important. If considering QoS required by emergency cases such as rescue, the key factor should be the availability. In sensor networks, battery life and energy conservation would be the prime QoS parameters. In real time applications, QoS requests can be expressed in term of many metrics in routing protocols. The most popular metrics are *data rate* and *delay*. To satisfy QoS requirements, the corresponding available data rate and delay that could be provided by the network of each route should be calculated in order to see which route could be used with satisfying QoS.

C. QoS Metrics

The QoS metrics can be classified into four categories as – *additive metrics, concave metrics, convex metrics,* and *multiplicative metrics*. Some of the metrics commonly used by applications to specify QoS requirements to the routing protocol are discussed here. The reference followed by the metric is a protocol that used the metric as a QoS constraint.

Minimum Required Throughput or Capacity – the desired application data throughput. QoS routing using this metric/constraint is [18].

Maximum Tolerable Delay (s) – maximum tolerable end-to-end delay for data packets [19].

Maximum Tolerable Delay Jitter – this is the difference between the upper bound on end-to-end delay and the absolute minimum delay [20]. This metric can also be expressed as delay variance [21].

Maximum Tolerable Packet Loss Ratio (PLR) – the acceptable percentage of total packets sent that are not received by the transport or higher layer agent at the destination [22].

Classifying protocols based on the QoS metric(s) is not simple as many of them utilize several metrics. Fig.3, presents a list of the more popular routing metrics and the protocols. A line connects each metric to every protocol which uses it for routing. Each protocol is linked to all metrics which it considers during route selection. This also illustrates which metrics are more popular by the number of protocols they are linked to.

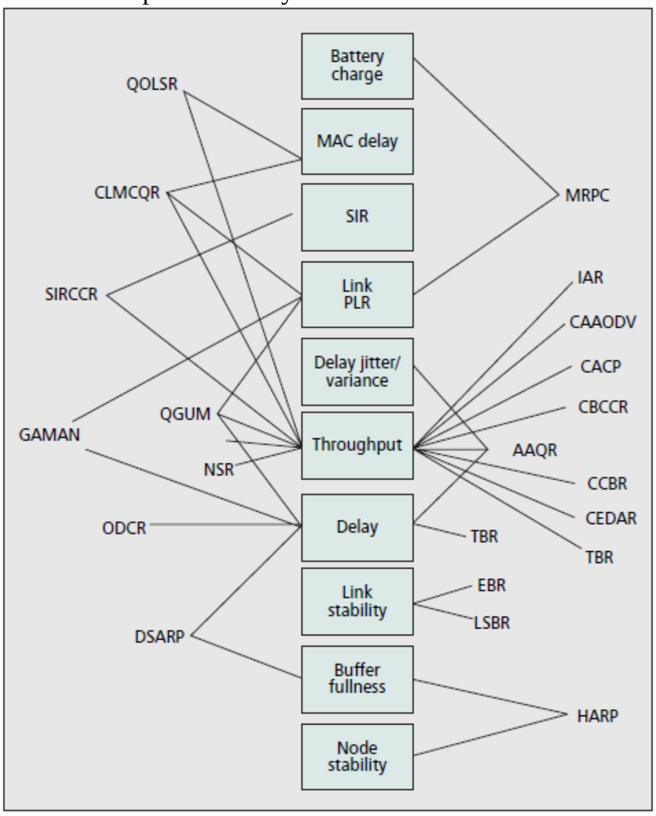

Fig. 3 Classification based on QoS metrics considered for route selection

D. QoS in different layers

The research on QoS support in MANETs spans over all the layers in the network. QoS models specify an architecture in which some kinds of services could be provided. It is the system goal that has to be implemented. QoS Adaptation hides all environment-related features from awareness of the multimedia-application above and provides an interface for applications to interact with QoS control. In *physical layer*, QoS means the quality in terms of transmission performance. Above the *network layer* QoS signaling acts as a control center in QoS support. The functionality of QoS signaling is determined by the QoS model. QoS routing is part of the network layer and searches for a path with enough resources but does not reserve resources [23]. QoS implemented in *MAC layer* could provide high probability of access with low delay when stations with higher user priority want to access the wireless medium. QoS MAC protocols are essential components in QoS for MANETs. In routing layer QoS implementation aims to find a route which provides the required quality [24]. QoS supporting components at upper layers, such as QoS signaling or QoS routing assume the existence of a MAC protocol, which solves the problems of medium contention, supports reliable communication, and provides resource reservation.

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IV. QOS AWARE ROUTING PROTOCOLS FOR MANETS

The QoS-aware routing protocols are supposed to determine a path from a source to the destination that satisfies the needs of the desired QoS. The QoS-aware path is determined within the constraints of *distance*, *bandwidth*, *minimal search,* and *traffic conditions*. As the selection of path is based on the desired QoS, the routing protocol can be termed QoS-aware. The QoS routing protocols are classified by [25]:

- Treatment of network topology – flat, hierarchical, or location-aware
- Approach to route discovery – proactive, reactive, hybrid or predictive.

According to [26] they are classified in to three different ways as follows:

- The interaction between the route discovery and QoS provisioning mechanism (coupled or decoupled)
- The interaction with the MAC layer (either independent or dependent)
- Again, on the approach to route discovery.

A. Core Extraction Distributed Ad Hoc Routing

The Core Extraction Distributed Ad Hoc Routing (CEDAR) algorithm was proposed in [27]. This algorithm is proposed for small to medium-sized ad hoc networks consisting of tens to hundreds of nodes. CEDAR algorithm has three key components:

Core extraction – A dynamic, self-organizing backbone routing infrastructure referred as *Core* is constructed. This used for performing route computations and topology management. A core is a set of nodes elected by approximating a Minimum Dominating Set (MDS) of the ad hoc network. All nodes are either part of this MDS or have a neighbor that is part of the set. The Fig 4 shows a simple core network in CEDAR. The shaded circles represent *core nodes* and unshaded stand for *non-core nodes*. The core is constructed by each node selecting a *dominator* from among its neighbors. The dominator is a neighbor node with the highest degree of connectivity. A node joins the core if it is selected b at least one node as dominator. In the figure the arrows point from node to the dominator.

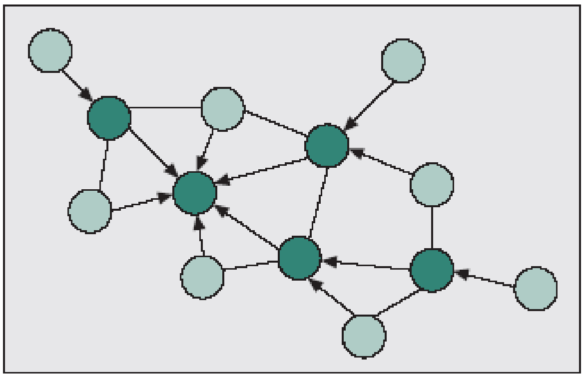

Fig. 4 Simple Core network found in CEDAR

Link State Propagation – After establishing the core, it incrementally propagates the link states of stable high-bandwidth links to the core nodes. Information about stable high bandwidth links is made known to nodes far away in the network, and information about the low bandwidth links remain local.

Route Computation – This is performed on demand, and is done by the core nodes using only local state. A Core path is established from the dominator of the source node to the dominator of the destination. Using the directional information provided by the core path, CEDAR iteratively tries to find a partial route from the source to the domain of the utmost possible node in the core path satisfying the requested bandwidth. This node then becomes the source of the next iteration. This process repeats until the destination is reached or the computation fails to find a suitable path.

The important features about this algorithm were the core broadcast and link capacity dissemination mechanisms. These make efficient use of network resources and relatively accurate and up-to-date knowledge of the QoS state where it is required. The drawback of this approach is that the total amount of updates needed to maintain the topology and state information makes this an undesirable due to random mobility patterns.

B. Spatial Reused Bandwidth Reservation

Spatial Reused Bandwidth Reservation (SRBR) algorithm is proposed in [28] used resource reservation and directional antenna technology. The Resource reservation in wireless networks is an essential component needed to support multimedia and real time applications, such as audio/video conferencing. Directional antenna technology provides the capability for considerable increase in spatial reuse that increases the efficiency of communication. In this approach the source node tries to discover multiple node-disjoint paths that are capable of satisfying the desired Quality of Service (QoS) requirement in ad hoc networks using directional antennas. Implementation of this SRBR shows that there is a significant gain in the performance with a decrease in the number of paths, as well as an increase in the percentage of successfully received data packets and reservation success rate.

C. Ad Hoc Quality of Service On-demand Routing

Ad hoc QoS On-demand Routing (AQOR) [29] provides end-to-end quality of service (QoS) support, in terms of bandwidth and end-to-end delay, in Mobile Ad hoc Networks (MANETs). QoS is provided in AQOR by integrating (1) on-demand route discovery between the source and destination, (2) signaling functions for resource reservation and maintenance, and (3) hop-by-hop routing.

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In AQOR, Neighborhood information is very important. This provides the local topology, traffic and mobility information. This is critical for traffic measurement, QoS violation detection and recovery. To maintain the neighborhood information, every node in the network periodically send out a ‘‘Hello’’ packet, announcing its existence and traffic information to its neighbors. In this, the route is discovered on-demand by propagating the route request and route reply packets between the source and the destination. The route discovery algorithm is implemented by route exploration from source to destination and route registration in the reverse path.

During route exploration there maybe multiple route request packets. Upon receiving each request packet, the destination will send back a reply packet to the source along the reverse route. When receiving the reply packet, each explored intermediate node will check its bandwidth availability again to reduce the possibility of transient routes. If the packet is accepted, the node will update the route status to registered. After registration, the nodes are ready to accept the real data packets of the flow. The admission control policy should guarantee the requested minimum flow bandwidth and the maximum end-to-end delay for each flow.

AQOR can provide sustainable QoS support to multimedia applications. It can quickly recover the route breaks and channel deterioration, minimizing their effect on QoS flows. In large mobile networks, AQOR dynamically adjusts its admission policy with the offered load and node mobility while keeping the delivery ratio of the admitted flow stable at above 95%.

D. Route Stability-based Multipath Quality of Service Routing

The Route Stability-based Multipath Quality of Service Routing (SMQR) is proposed in [30] to support routing stability along with throughput and delay in MANETs. The main components in the proposed algorithm are

1) A model for computing route stability based on received signal strengths and using the model to choose QoS routes that endure longer time.

2) A route stability-based QoS-aware multipath route discovery mechanism with a special route request forwarding rule to reduce request forwarding rule to reduce the path diminution problem.

3) Incorporation of a hop-by-hop admission control and a soft resource reservation in the route discovery procedure.

4) A method to select a primary path and two other secondary paths (if possible) which are node disjoint.

5) A route maintenance mechanism to handle QoS violation and for the maintenance of secondary paths; and

6) A proactive path switching by the source, so that the highest stable route among the multiple paths is always selected for transporting data. This is achieved through path quality values obtained from periodic route maintenance.

In this protocol, a periodic maintenance and validation of the alternate paths is performed. If the stability value of the alternate route is higher than that of the primary route, then the primary route is switched to the alternate route. A new route discovery is initiated only when all the paths in the multipath fail. When a QoS routing path is discovered, the source admits real-time traffic into the primary path. To reduce QoS disruptions, route is maintained in two ways – QoS violation on the active primary path and other is continuous maintenance of alternate paths to ensure that only valid paths are maintained. This multipath routing significantly reduces the number of route recoveries required during QoS data transmission. Detection of route failure and switching to a stable route before actual route break saves route recovery time and reduces packet loss.

E. Hybrid Hop Count-based Multiple Quality of Service Constraints Routing Protocol with Mobility Prediction

Hybrid Hop Count-based Multiple Quality of Service constraints Routing Protocol with Mobility Prediction (HMQRPMP) is a source-based hybrid routing protocol proposed in [31]. This protocol deals with QoS parameters like delay, delay-jitter, bandwidth, cost, link expiry time and residual battery power of mobile nodes. HMQRPMP selects the best routing path with minimal hop count, maximal link expiry time and high energy level among multiple paths between a source and a destination as to increase packet delivery ratio and reduce control overhead in MANET.

HMQRPMP changes the behavior of a mobile node from proactive to reactive or vice versa by comparing the nodes energy level against the power thresholds so as to be adoptable to topological changes which increases the lifetime of mobile nodes in MANET. This algorithm predicts the stability of Link Expiry Time by altering the well known mobility prediction formula using mobility adjustment factor which in turns reduces the number of failures in data transmission and produces significant improvement in data transmission rate. It provides a quick response to topological changes in the network with minimal control overhead. As this protocol considers almost many of the user specific QoS constraints, it can be considered as a common framework suitable for all MANET applications.

V. CONCLUSION

In this paper we reviewed the challenges and basic concepts behind QoS routing in MANETs and provided a thorough overview of QoS routing metrics and design considerations. MANETs are likely to expand their applications in the future communication environments. The support for QoS will thus be an important and desirable component of MANETs. Several important research issues and open questions need to be addressed to facilitate QoS support in MANETs. Capacity estimation, route discovery, route maintenance and feasible path selection are key issues that require further exploration.

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