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Mobile Ad Hoc Networks: A detailed Survey of QoS Routing Protocols

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Abstract

This paper shows a detailed overview of QoS routing metrics, resources, and factors which are affecting performance of QoS routing protocols. The relative strength, weakness, and applicability of existing QoS routing protocols are also studied and compared. QoS routing protocols are classified according to the QoS metrics.

Keywords

MANETs, Quality of Service (QoS), routing protocol, mobile node.

1. Introduction

A mobile ad hoc network (MANET) [1] is defined as an autonomous system of mobile nodes and associated hosts connected by wireless links. Every node operates not only as an end-system, but also as a node to forward the packets in appropriate direction. All the nodes are free to move and organize themselves into a network. The important use of mobile ad hoc network is in battlefield. MANETs do not require the support of wired access points or base stations for intercommunication. A mobile ad hoc network, unlike a static network, has no infrastructure. It is a collection of mobile nodes where communication is established in the absence of any fixed foundation. The only possible direct communication is between neighboring nodes. Therefore, communication between remote nodes is based on multiple-hop.

These nodes are dynamically located in such a way that the interconnections between nodes are capable of changing on a continual basis. MANETs are self-configuring; there is no central management system with configuration responsibilities. All the mobile nodes can communicate each other directly, if they are in other's wireless links radio range. Since MANETs allow ubiquitous service access, anywhere, anytime without any fixed infrastructure they can be widely used in military battlefields, crisis management services, classrooms and conference halls etc. MANETs ad-hoc fashion networking developments lead to development of multimedia applications such as video-on-demand, video conferencing etc. Routing protocols for this kind of wireless network should be able to maintain paths to other nodes and, in most cases, must be handle changes in paths due to mobility. Though, most of the available routing protocols do not consider the QoS problem. QoS is the performance level of a service offered by the network to the user. Most of the multimedia applications have stringent QoS requirements that must be satisfied. The goal of QoS provisioning is to achieve a more deterministic network behavior, so that information carried by the network can be rightly delivered and network resources can be better utilized. However, there still remains a significant challenge to provide QoS solutions and maintain end-to-end QoS with user mobility. Most of the conventional routing protocols are designed either to minimize the data traffic in the network or to minimize the average hops for delivering a packet. [1].

Even some protocols such as Ad-hoc On demand Distance Vector (AODV) [2], Dynamic Source Routing (DSR) [3] and On-demand Multicast Routing Protocol (ODMRP) [4] are designed without explicitly considering QoS. When QoS is considered, some protocols may be unsatisfactory or impractical due to the lack of resources and the excessive computation overhead. QoS routing usually involves two tasks: collecting and maintaining up-to-date state information about the network and finding feasible paths for a connection based on its QoS requirements. To support QoS [5], a service can be characterized by a set of measurable pre-specified service requirements such as minimum bandwidth, maximum delay and maximum packet loss rate.

A remaining part of this paper is organized as follows. In Section 2, we have discussed related works in terms of QoS routing surveys. A formal examination of the many challenges faced by the provision of QoS on the MANET environment is given is section 3. In section 4, we have analyzed the QoS routing metrics commonly used by all applications and the tradeoffs involved in the protocol design. Section 5 and 6 presents the scientific classification of QoS routing protocols based on their network architecture, type of QoS guarantee assured and the interaction with the MAC layer. Following this, we summarize and compare the operations, key features and major advantages and drawbacks of a selection of QoS routing protocols proposed in the literature.

2. Related Works

A moderately comprehensive overview of the state of the field of QoS in networking was provided by Chen [6]. Chakrabarti and Mishra [7] later summarized the important QoS related issues in MANETs in 2001 and their conclusions highlighted several significant points in MANET research. It includes admission control policies and protocols, QoS robustness and QoS preservation under failure conditions.

Al-Karaki et al. in 2004 published a detailed overview [8] and the development trends in the field of QoS routing. They highlighted some areas such as security and multicast routing requiring further research attention. They were categorized the QoS routing solutions into various types of approaches: Flat, Hierarchical, Position-based and power aware QoS routing. Reddy et al. [9] provided a complete overview of the more widely accepted MAC and routing solutions for providing better QoS in MANETs.

3. Issues and Challenges While Providing QOS in Ad-hoc Networks

Mobile ad hoc networks differ from the traditional wired networks. They have certain unique characteristics which cause difficulties for providing QoS in such networks. The unique characteristics are dynamically varying network topology, lack of precise state information, shared radio channel, limited resource availability, hidden terminal problem and insecure medium. These characteristics and their effects on ad hoc networks will be discussed in this part one by one.

i. Dynamically varying network topology

In mobile ad hoc networks, nodes are mobile and network topology is changing dynamically. Consequently, the route which is already set up with required QoS could not satisfy QoS anymore if one of the nodes on this established route moves. For example, a node could move to an area with more interference to it. The node whose data rate has been overused should take some actions. The information about loss of QoS should be sent by this node to all sources whose transmission is going through the overloaded node. Sources who receive this message have to find another possible route by using QoS aware routing protocol again. This procedure will cause delay which may not be acceptable.

ii. Lack of precise state information

Due to the dynamic characteristic, information of nodes transmitted to other nodes may change right after this information is transmitted to its neighbors. The information here can be the data rate available at the neighboring node, since available data rate of nodes is affected by the data rate of its neighbors. As a result, this information which is already transmitted may have been out of date and it may lead to a wrong routing decision.

iii. Shared radio channel

Data transmitted on the radio channel can be received by stations which are in the carrier sensing range of the transmitter. This broadcast characteristic will cause interference to other stations when traffic is transmitted over the air interface. Thus, stations have to share channel with neighbors in their carrier sensing range. This is very different from the wired channel which will not cause that much interference between each other because of proper construction of lines that attenuates crosstalk interference significantly.

iv. Limited resource availability

The resources such as data rate, battery life, and storage space are all very limited in ad hoc networks. The battery life in a sensor network is a very good example. In a sensor network, each sensor has very limited battery life, so routing based on power consumption is widely considered. The data rate is very limited for wireless links if we compared it with the data rate available in wired network. In addition, the basic characteristics of the wireless channel e.g. fading, noise, and shared data rate between neighbor nodes (neighbor nodes have to keep silent when it senses some node is transmitting) will also degrade the wireless data rate The actual radio data rate becomes much smaller. As a result, it is hard for a wireless network to provide too high data rate which could be provided by the wired network. It also brings problem of cooperation between wireless network and wired network.

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4. Evaluation Metrics for QOS Routing Protocols

The set of constraints we adjust or control for a certain link to satisfy the requirements for a certain application are known to be the QoS metrics. As we know that different applications have different requirements, and the services required by them and the associated QoS parameters differ from application to application. For example, in case of multimedia applications, required bandwidth, delay and delay-jitter (delay variation) and packet loss are the key QoS parameters, whereas military applications have strict and demanding security requirements. The following is a sample of the metrics commonly used by applications to specify QoS requirement to the routing protocol.

i. Minimum Throughput (bps) – the required application data throughput. [13]

ii. Maximum Delay (s) – maximum tolerable end-to-end delay for data packets. [14]

iii. Maximum Delay jitter – difference between the upper bound on end-to-end delay and the absolute minimum delay. [15]

iv. Maximum Packet loss ratio - the acceptable percentage of total packets sent, which are not received by the final destination node. [16]

The value of a metric over the entire path can be one of the following compositions [25][26]:

i. **Additive metrics-** This can be represented mathematically as follows:

$$m(p) = \sum_{i=1}^{LK} m(lk_i)$$

Where *m (p)* is the total of metric *m* of path *(p)*, *lki* is a link in the path *(p), LK* is the number of links in path *(p)*, and *i= 1,…LK* Delay, delay variation (jitter), and cost are examples of this type of composition. Various factors that determine the delay in communication networks are reviewed in [23].

ii. **Concave metrics-** This can be represented mathematically as follows:

$$m(p) = \min(m(lk_i))$$

Bandwidth is an example of this type of composition. The bandwidth we are interested in here is the residual bandwidth that is available for new traffic. It can be defined as the minimum of the residual bandwidth of all links on the path or the bottleneck bandwidth.

iii. **Multiplicative metrics.** This can be represented mathematically as follows:

$$m(p) = \prod_{i=1}^{LK} m(lk_i)$$

Loss probability is an indirect example of this type of composition.

iv. **Convex metrics:** This can be represented as the maximum of all metric along the path *m(p)=max (m(lki))*

Vulnerability (in context of security) and throughput use the convex rule. Whatever the metrics used in determining the path, these metrics must represent the basic network properties of interest. These metrics include residual bandwidth, delay, and jitter. Since the flow QoS requirements have to be mapped onto path metrics, therefore the metrics define the types of QoS guarantees the network can support.

5. Criteria of QoS Routing Protocols Classification

Routing protocols in ad hoc networks varied depending on the type of the network. Typically, ad hoc network routing protocols are classifiable into three major categories based on the routing information updated mechanism as shown in Figure 1. They are

- Proactive (table driven routing protocols)
- Reactive (on-demand routing protocols)
- Hybrid routing protocols [35]

In addition, protocols can also be divided according to the utilization of specific resources, such as power aware routing protocol and load aware routing protocols and so on.

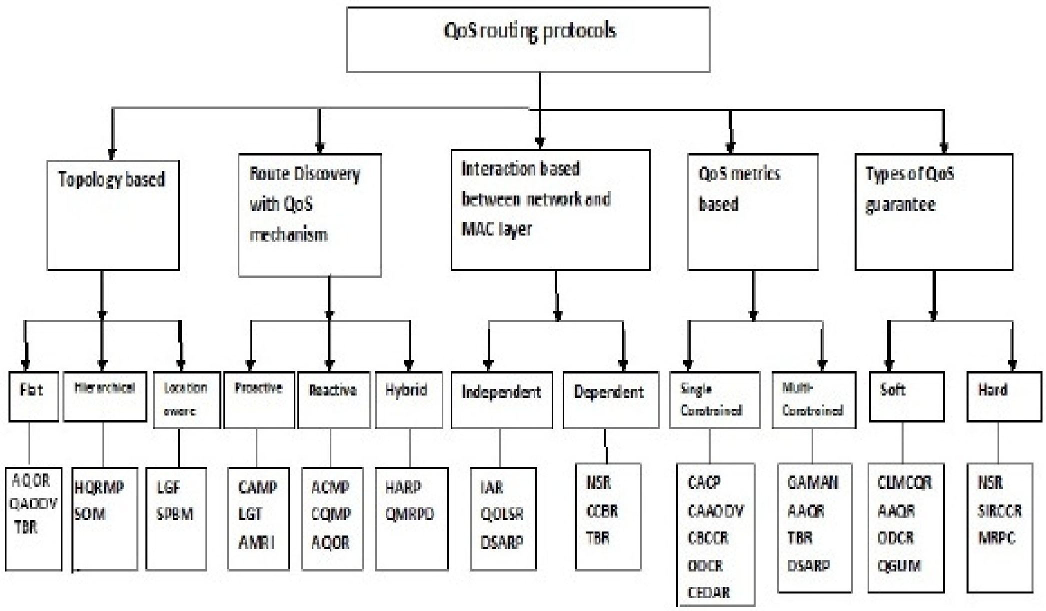

Fig-1 QOS Routing Protocols Classification

Route Discovery with QoS based protocols

Based on the routing information update mechanism employed, QoS approaches can be classified into three categories viz., Proactive, on-demand, and hybrid QoS approaches. Proactive protocols are one where a routing table is maintained at every node which aids in forwarding packets. These tables are updated frequently in order to manage up-to-date routing information from each node to other node.

There are some typical proactive QoS routing protocols such as QOLSR [23] (QoS Optimized Link State Routing) and PLBQR [24] (Predictive Location-Based QoS Routing in Mobile Ad Hoc Networks). A reactive protocol is also called "on-demand" protocols. Reactive protocols are one which does not require the maintenance of network topology when there is no traffic. The state information is acquired when needed. However, route maintenance is an important operation of reactive routing protocols, because source nodes may suffer from long delays for route searching before they can forward data packets. QoS AODV [25] (QoS Ad-hoc on demand Distance Vector), ACMP [26] (Adaptive Core based Routing Protocol with Consolidated Query Packets) and CQMP (Mesh-based Multicast Routing Protocol with Consolidated Query Packets) are typical examples for reactive routing protocols. Compared to proactive routing protocols, less control overhead is the significant advantage of the reactive routing protocols. A hybrid protocol as the name implies it is a combination of both proactive and reactive strategies. Hence, hybrid protocols address both efficiency and robustness. The Efficient hybrid Multicast Routing Protocol (EHMRP) [26] is an instance for hybrid-based QoS routing protocol.

Single constrained vs. Multi constrained QoS metrics

Most of the protocols focused on providing an assured throughput service only, since Throughput was deemed the most important requirement in earlier days. These single-constrained routing protocols have received success in many aspects; however, they do not always perform best. In CEDAR the bandwidth is used as the only QoS parameter for routing. Most of the multimedia applications require the communication to meet stringent requirements on delay, delay-jitter, cost and other QoS metrics. In these circumstances, the trend is to move from single constrained routing to multi constrained routing. The main function of multiconstrained QoS routing is to find a feasible path that satisfies multiple constraints simultaneously, which is a big challenge for MANETs where the topology may vary constantly, is a NP-complete problem. QMRPD (QoS Multicast Routing Protocol for Dynamic group topology) [33] GAMAN (Genetic Algorithm-based routing for MANETs) [34] HMCOP (Heuristic multi Constrained Optimal Path) are typical multi constrained routing protocols.

Hard QoS vs. Soft QoS approach

If QoS requirements of a connection are guaranteed to be met for the whole duration of the session, the QoS approach is termed as *hard QoS* approach. In MANETS it is very challenging to provide hard QoS guarantees to user applications. Some of the protocols NSR and SIRCCR (SIR and Channel Capacity based Routing). If the QoS requirements are not guaranteed for the entire session, the QoS approach is termed as *soft QoS* approach. Thus, QoS guarantees can only be given within certain statistical bounds. Most of the protocols provide soft QoS guarantees. Hard QoS provided by networking technologies such as ATM is a superior way of dividing up network resources to regulate traffic. The main advantage of hard QoS over soft QoS is guaranteed bandwidth, soft QoS has been proven to be a viable and reliable competitor to hard QoS, but However at a lower cost.

6. QOS-Aware Routing Protocols

The primary goal of the QoS-aware routing protocols is 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 bandwidth, minimal search, distance, and traffic conditions. Since path selection is based on the desired QoS, the routing protocol can be termed QoS-aware. In the literature, numerous routing protocols have been proposed for finding QoS paths. In the following sections some of these QoS routing protocols are described.

6.1. Core Extraction Distributed Ad hoc Routing (CEDAR)

The Core-Extraction Distributed Ad hoc Routing (CEDAR) algorithm is proposed for QoS routing in ad hoc networks. Bandwidth information is advertised by elected subset nodes along with their link state updates, to identify and avoid congested parts of the network. When a link fails, CEDAR's route re-computation confines itself to the immediate neighborhood of the breakage. CEDAR has three key components:

(a) The establishment and maintenance of a self-organizing routing infrastructure called the *core* for performing route computations.

(b) The propagation of the link-state of high-bandwidth and stable links in the core through *increase/decrease waves*.

(c) A QoS route computation algorithm that is executed at the core nodes using only locally available state.

Core extraction: A set of nodes is elected to form the core that maintains the local topology of the nodes in its domain, and also to perform route computations. The core nodes are elected by approximating a minimum dominating set1 of the ad hoc network.

Link state propagation: QoS routing in CEDAR is obtained by propagating the bandwidth availability information to every core node. The basic idea is that the information about stable high bandwidth links can be made known to nodes far away in the network.

***Route computation**:* A core path is established first from dominator (neighboring core node) of source to dominator of destination. Using up-to-date local topology and the directional information provided by the core path, CEDAR iteratively tries to find a partial route from the source to the domain of the possible node in the core path satisfying the requested bandwidth. This node then becomes the source of the next iteration. In the CEDAR approach, the core provides an efficient low-overhead infrastructure to perform routing, while the state propagation mechanism ensures availability of link state information at the core nodes without incurring high overheads.

6.2. Multipath Routing Protocol (MRP)

MRP is a reactive on-demand routing Protocol which extends DSR protocol to find multipath routing coupled with bandwidth and reliability constraint. It consists of three phases: routing discovery, routing maintenance and traffic allocation. In routing discovery phase, the protocol selects several multiple alternate paths which meet the QoS requirements and the ideal number of multipath routing is achieved to compromise between load balancing and network overhead. In routing maintenance phase, it can effectively deal with route failures similar to DSR.Furthermore, the per-packet granularity is adopted in traffic allocation phase.

6.3. Genetic Algorithm-Based QoS Routing Protocol for MANETS (GAMAN)

A Genetic Algorithm-based source-routing Protocol for MANETs (GAMAN) is proposed, which uses end-to-end delay and transmission success rate for QoS metrics. Genetic Algorithms (GAs) may be employed for heuristically approximating an optimal solution to a problem, in this case finding the optimal route based on the two QoS constraints mentioned. The first stage of the process involves encoding routes so that a GA can be applied; this is termed gene coding. For this purpose, paths are discovered on-demand and then a network topology view is constructed in a logical tree-like structure. Each node stores a tree routed at itself with its neighbor nodes as child nodes and in turn their neighbor nodes as their children. The route discovery algorithm is assumed to collect locally computed metrics such as average delay over a link and the link reliability for the links on each path. After the gene encoding stage, the fitness *T* of each path is calculated as follows:

$$T=\frac{\sum_{i=1}^{n} Di}{\prod_{i=1} Ri}$$

where *Di* and *Ri* are the delay and reliability of link *i*, respectably. The fitness values are used to select paths for cross-over breeding and mutation operations. The fittest path (with the smallest *T*) and the offspring from the genetic operations are carried forward into the next generation. While this method is a useful heuristic for approximating the optimal value over the delay and link reliability metrics at the same time, it requires many paths to be searched in order to collect enough “genetic information” for the GA operations to be meaningful. This means that the method is not suited to large networks

6.4. Predictive Location-Based QoS Routing in Mobile Ad Hoc Networks (PLBQR)

It is a location aware QoS routing protocol in which a location-delay prediction scheme, based on a location-resource update protocol has been performed. The location updates contain resource information pertaining to the node sending the update. This resource information for all nodes in the network and the location prediction mechanism are together used in the QoS routing decisions. There are dynamic changes in topology and resource availability due to the high degree of mobility of nodes in the ad hoc network. Due to these changes, the topological and routing information used by current network protocols is rendered obsolete very quickly. The advantage of this system is the prediction of new location based on previous location is made when there is variation in the geographical location. QoS routing based on the resource availability at the intermediate nodes in the source to destination route is performed which is rare in other location based routing scheme. But, accurate prediction on velocity and direction is not made when there are dynamic changes in the direction. The transmission is made only in linear pattern (i.e., angular velocity is kept as zero).

6.5 Hybrid routing protocol-Zone Routing Protocol (ZRP)

Zone Routing Protocol (ZRP) is a popular hybrid routing protocol today. It efficiently & effectively combines the benefits of both proactive and reactive routing protocols. The basic concept used in this protocol is to use a proactive routing within a zone in the r-hop neighborhood of every node and use a reactive routing for nodes outside this zone. The table driven scope is limited within a zone and when a destination is out of the table driven scope, on demand routing search is initiated. In this condition, control overhead is reduced.

6.6 QoS Multicast Routing Protocol with Dynamic group topology (QMRPD)

The QMRPD is a hybrid protocol which reduces significantly the overhead of constructing a multicast tree in order to fulfill the needs of multiple QOS constraints. The main objective is to satisfy the multiple QOS constraints with lower cost requirements. Its main function is to build a multicast tree that satisfy a certain objective function such as end to end delay bound, minimum bandwidth available and maximum packet loss probability. The main function is to minimize the overall cost of the tree.

6.7 QoS Optimized Link State Routing (QOLSR)

OLSR protocol [34] is a proactive routing protocol. Due to its proactive nature, it has a low setup time when a route is asked. In addition, it employs an efficient link state packet forwarding mechanism called multipoint relaying, so this protocol is an optimization of the pure link state protocol. The optimization is achieved by reducing the size of the control packets and by reducing the number of links that are used to forward the link state packets. The Optimized Link State Routing (OLSR) protocol [23] is a proactive link state routing protocol for MANETs. One key idea is to reduce control overhead by reducing the number of broadcasts as compared with pure flooding mechanisms. The basic concept to support this idea in OLSR is the use of multipoint relays (MPRs) [23, 27]. MPRs refer to some routers that can forward broadcast messages during the entire flooding process. To reduce the size of broadcast messages, every router declares only a small subset of all of its neighbors. The protocol is specifically suitable for large and dense networks [23]. MPRs act as intermediate routers in route discovery procedures. Hence, the path discovered by OLSR may not be the shortest path. This is a potential disadvantage of OLSR.

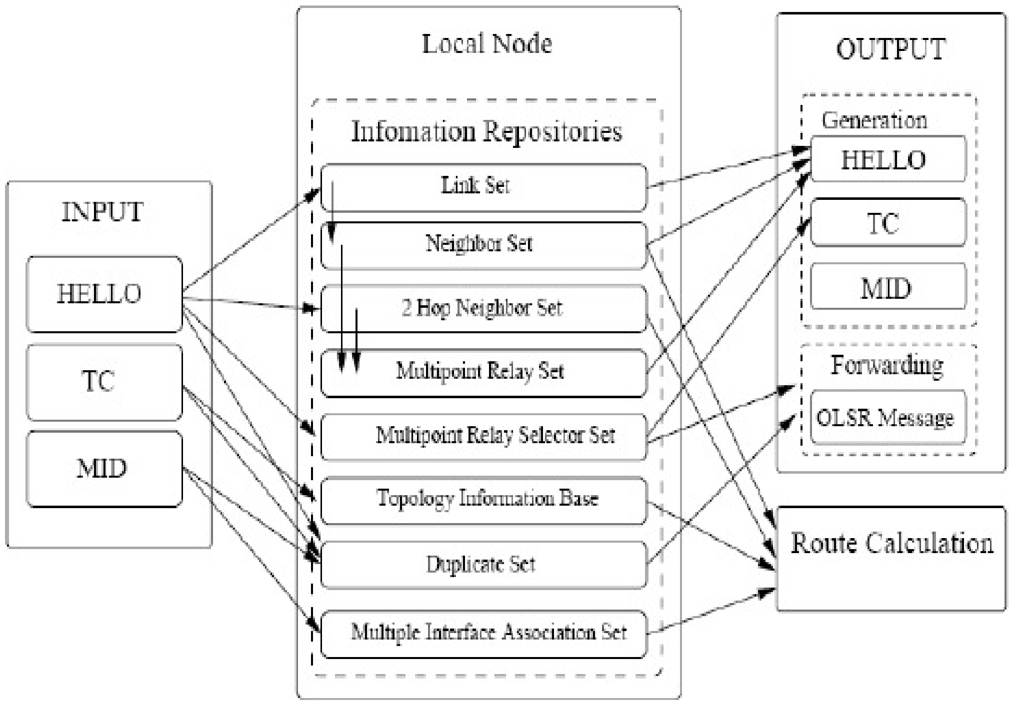

Fig-2 OLSR information repositories relation overview

OLSR has three functions: packet forwarding, neighbor sensing, and topology discovery. Packet forwarding and neighbor sensing mechanisms provide routers with information about neighbors and offer an optimized way to flood messages in the OLSR network using MPRs. If nodes with low data rate are selected, there will be higher possibility of overloading at this node. The link with larger data rate should have more probability to be involved in the MPR set. The selection of the optimal MPR set is NP-complete. It is what QoS based OLSR routing protocol considered. The neighbor sensing operation allows routers to diffuse local information to the whole network. Topology discovery is used to determine the topology of the entire network and calculate routing tables. OLSR uses four message types: Hello message, Topology Control (TC) message, Multiple Interface Declaration (MID) message, and Host and Network Association (HNA) message. Hello messages are used for neighbor sensing. Topology declarations are based on TC messages. MID messages contain multiple interface addresses and perform the task of multiple interface declarations. Since hosts that have multiple interfaces connected with different subnets, HNA messages are used to declare host and associated network information. Extensions of message types may include power saving mode, multicast mode, etc.

6. Ad hoc QoS on Demand routing (AQOR)

AQOR [33] uses a reservation-oriented method to provide QoS guarantees. The protocol provides a strategy for dynamically constructing paths between mobile nodes that form a MANET. The signaling of AQOR allows for both route discovery and end-to-end QoS reservation (minimum bandwidth and maximum delay). AQOR detailed computations to find the available bandwidth and end-to-end delay in unsynchronized wireless environment. By using the proposed mechanisms it is possible to make an admission control of flows based on the available resources (bandwidth and end-to-end delay), and to easily apply fast recovery on

QoS violation situations. The protocol works in several ways to allow QoS routing: neighbor discovery and maintenance, route exploring, route registering (for explored routes), a bandwidth reservation mechanism based on the arrival of the first packet of a flow, releasing of registered resources (but not reserved), a loop-free routing mechanism and the already mentioned mechanisms for admission control and bandwidth calculation.

7 Summary of QOS Routing Protocols

Comparison among the different QoS-aware routing protocols, is described in a table. The table [30] lists the design constraints listed earlier such as Route discovery, Resource reservation, Route maintenance, QoS metrics constrained, Network architecture and routing overhead and discussing how each protocol addresses.

Routing protocol	**Network Architecture**	**Route discovery**	**Type of QoS guarantee**	**Resource reservation**	**QoS metrics**	**Routing overhead**
CEDAR	Hierarchical	Proactive/ Reactive	Soft	Yes	Bandwidth	core setup
MRP	Hierarchical	Reactive	Soft	Yes	Bandwidth	Full flooding of RREQ
GAMAN	Hierarchical	Reactive	Soft	Yes	Bounded delay, packet loss rate	Node traversal delay
PLBQR	Location Prediction	Proactive/ Reactive	Soft	No	Delay, and Bandwidth	Route recomputation in anticipation of link
QMRPD	Hierarchical	Reactive	Pseudo-hard	Yes	Bandwidth, Delay, Delay-jitter and cost	Less message processing overhead
QOLSR	Hierarchical	Proactive	Soft	Yes	Throughput and Delay	Minimum flooding of RREQ
AQOR	Flat	Reactive	Soft	Yes	Bandwidth, Delay	Full flooding of RREQ
TBR	Flat	Reactive	Soft	Yes	Bandwidth, Delay	Minimum flooding of RREQ
QAODV	Flat	Reactive	Soft	No	Bandwidth, Delay	Node traversal delay

8. Conclusion & Future Challenges

In this paper, an effort has been made to develop comparative study and performance analysis of various on demand/reactive routing protocols on the basis of mentioned performance metrics. 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. Energy efficiency is one of the main problems in a mobile ad hoc network, especially designing a routing protocol. Power control and accommodating multiple classes of traffic requires further research attention. Further we can say that due to decentralized characteristics, dynamically changing topology, it is too difficult to achieve security and power management in MANETs. Future research work and effort will be made to discover an efficient power aware routing scheme in MANETs which can support both real and non real time traffic.

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