A Review of Quality of Service (QoS) Routing Protocols for Mobile Ad hoc Networks

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Abstract*—A mobile ad hoc network (MANET) consists of a collection of mobile nodes that communicate in a multi-hop way without a fixed infrastructure. Owing to its uniqueness such as easy deployment and self-organizing ability, it has shown great potential in many civil and military applications. As MANETs are gaining popularity, their need to support real time and multimedia applications is rising as well. Such applications have Quality of Service (QoS) requirements like bandwidth, end-to-end delay, jitter and energy. Consequently, it becomes very necessary for MANETs to have an efficient routing and QoS mechanism to support these applications. QoS provisioning for MANET can be done over different layers starting from the physical layer up to the application layer. This paper mainly looks at the problem of QoS provisioning in the perception of network layer. QoS routing aims at finding a feasible path that satisfies QoS constraints like bandwidth, end-to-end delay, jitter, energy etc. This paper provides a detailed survey of QoS routing protocols in MANETs.

Keywords— MANET, QoS, Routing metrics and Optimization

I. INTRODUCTION

QoS provisioning can be done over different layers in the protocol stack, starting from the physical layer up to the application layer. Each layer takes cares of different measurements in QoS provisioning. For example, the physical layer takes care of transmission quality. The link layer handles the variable bit error rate. The network layer deals with the change in bandwidth and delay. The transport layer focuses on the delay and packet loss due to transmission errors. The application layer aims at the frequent disconnections and reconnections [1].

The signal-to-noise ratio of wireless medium in mobile ad hoc networks fluctuates with respect to time. Therefore, adaptive modulation is required to alter many parameters based on the current channel state to obtain better performance from wireless medium. As a result, one of the major challenges in supporting QoS over wireless medium is channel estimation. It includes perfect channel estimation in the receiver and reliable feedback of the estimation to the transmitter .Therefore, the transmitter and receiver can be properly synchronized. Because of the time-varying fading channel, coding schemes developed for a fixed channel are not suitable for MANETs.

The Medium Access Control (MAC) protocol determines which node should transmit next on the broadcast channel when several nodes are competing for transmission on that channel. The existing MAC protocols for ad hoc wireless networks use channel sensing and random back-off schemes, making them suitable for best-effort data traffic. MAC layer aims at providing QoS guarantee for real-time traffic support. One of the main problems which occurred in MANETs was the hidden and exposed terminal problems. This can be handled by a fully distributed scheme. Multihop Access Collision Avoidance (MACA) has been proposed by Karn to solve the problem by using Request-o-Send and Clear-To-Send (RTS/CTS) dialogs [2]. This scheme does not completely eliminate the hidden terminal problem. So an extended approach, namely, MACA for Wireless (MACAW) was proposed to provide faster recovery from hidden terminal collisions [3].

QoS implemented in the network layer aims at finding a route which provides the required quality. The metrics used to select the route are not only the number of hops along the route but also other metrics like delay, bandwidth, network life time and data rate. QoS routing is a scheme that takes into consideration the appropriate information about each link. Based on that information it selects paths that satisfy the QoS requirements of a flow. QoS routing protocols have a key part in a QoS mechanism, because it is their function to find nodes that can serve the application's requirements. Many routing protocols have been developed to discover and retain routes between source and destination nodes. The main objective of the QoS routing protocols is to establish a path from a source to the destination that satisfies the needs of the desired QoS. These protocols work with the resource management methods to establish paths through the network that meets end-to-end QoS requirements.

The rest of the paper is organized as follows. Section two gives the fundamentals of QoS routing protocols. Section three explains the single metric QoS routing protocols. Section four describes multiple metrics QoS routing protocols. Section five elaborates on QoS routing protocols using optimization techniques. Section six concludes our review.

II. QOS ROUTING PROTOCOLS

QoS routing protocols search for routes with sufficient resources in order to satisfy the QoS requirements of a flow. The information regarding the availability of resources is managed by a resource management module, which assists the QoS routing protocol in its search for QoS feasible paths. The QoS routing protocol should find the path that consumes minimum resources [1].

To assist QoS routing, the topology information can be maintained at the nodes of ad hoc wireless networks. The topology information needs to be refreshed frequently by sending link state update messages, which consume precious network resources such as bandwidth and battery power. Otherwise, the dynamically varying network topology may cause the topology information to become imprecise. This trade-off affects the performance of the QoS routing protocol. As path breaks occur frequently in ad hoc wireless networks, compared to wired networks where a link goes down very rarely, the path satisfying the QoS requirements needs to be recomputed every time the current path gets broken. The QoS routing protocol should respond quickly in case of path breaks and recompute the broken path or bypass the broken link without degrading the level of QoS.

This is a complex and difficult issue because of the dynamic nature of the network topology and generally imprecise network state information [4]. Depending on the application involved, the QoS constraints-bandwidth, cost, end-to-end delay, delay variation (jitter), energy, probability of packet loss and so on could be available. Only a few QoS routing protocols have been proposed so far MANETs, most of which are outlined in the following sections.

III. Single Metric QoS Routing Protocols

A. Bandwidth

The first major work on MANET QoS was the INSIGNIA framework proposed in [5], where resources are reserved in an end-to-end manner through a Resource Reservation Protocol (RSVP). This QoS framework is designed to support adaptive services as a primary goal in ad hoc networks. It allows packets of audio, video and real-time data applications to specify their maximum and minimum bandwidth needs and plays a central role in resource allocation, restoration control and session adaptation between communicating mobile hosts. Based on availability of end-to-end bandwidth, QoS mechanisms attempt to provide assurances in support of adaptive services.

To support an adaptive service, the INSIGNIA framework establishes and maintains reservations for continuous media flows and micro-flows. To support these communication services, the INSIGNIA QoS framework comprises a number of architectural components, namely in-band signalling, admission control, packet forwarding, routing protocol, packet scheduling and Medium Access Control (MAC). A key component of this QoS framework is the INSIGNIA signalling system–an RSVP like signalling system that supports fast reservation, restoration and adaptation algorithms that are specifically designed to deliver adaptive service. The admission control module is responsible for allocating bandwidth to flows based on the maximum and minimum bandwidth requested. Once resources have been allocated, they are periodically refreshed by a mobile soft-state mechanism through the reception of data packets. The packet-forwarding module classifies incoming packets and forwards them to the appropriate module.

The Core Extraction Distributed Ad hoc Routing (CEDAR) algorithm proposed [6]. It dynamically establishes the core of the network and then incrementally propagates the link states of stable high bandwidth links to the nodes of the core. The route computation is on-demand basis and is performed by the core nodes using only local state. CEDAR has three key components:

1) 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 performs route computations. The core nodes are elected by approximating a minimum dominating set of the ad hoc network.

2) Link state propagation

QoS routing in CEDAR is achieved by propagating the bandwidth availability information of stable links in the core. The basic idea is that the information about stable high-bandwidth links can be made known to nodes far away in the network, while information about the dynamic or low bandwidth links remains within the local area.

3) Route computation

Route computation first establishes a core path from the domain of the source to the domain 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 furthest 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 and low-overhead infrastructure to perform routing, while the state propagation mechanism ensures the availability of link-state information at the core nodes without incurring high overheads. The bandwidth is used as the only QoS parameter for routing.

An available bandwidth calculation algorithm for ad hoc networks with Time Division Multiple Access (TDMA) for communications has proposed [7]. This algorithm involves end-to-end bandwidth calculation and bandwidth allocation. Here, only bandwidth is considered to be the QoS parameter. Using this algorithm, the source node can determine the resource availability for supporting the required QoS to any destination in MANETs. In TDMA systems, time is divided into slots, which in turn are grouped into frames. Each frame contains two phases: control phase and data phase. During the control phase, each node takes turns to broadcast its information to all of its neighbors in a predefined slot. Therefore, at the end of control phase, each node learns the free slots between itself and its neighbors. Based on this information, bandwidth calculation and assignment can be performed distributively.

An admission control scheme over an On-demand QoS Routing (OQR) protocol to guarantee bandwidth for real-time applications was proposed [8]. Since routing is on-demand in nature, there is no need to exchange control information periodically and maintain routing tables at each node. The network is time-slotted and bandwidth is the key QoS parameter. The path bandwidth calculation algorithm proposed in BR is used to measure the available end-to-end bandwidth. OQR protocol uses an on-demand resource reservation scheme and hence produces lower control overhead.

Reference [9] suggested a multi-path QoS routing protocol. This protocol attempts to discover multiple paths that jointly satisfy the bandwidth requirements. The original bandwidth request is essentially split into several sub-bandwidth requirements. Each sub-path is then accountable for one sub-bandwidth requirement. This protocol is on-demand and it uses the local bandwidth information available at each node for discovering routes. A ticket-based approach is used to search for multiple paths. In this method, a number of probes are sent out from the source, each carrying a ticket. Each probe is responsible for searching one path.

The number of tickets sent controls the amount of flooding that is done. Each probe travels along a path that contains the necessary bandwidth. The source initially sends a certain number of tickets each containing the total bandwidth requirement. The tickets are sent along links that contain sufficient bandwidth to meet the requirement. When an intermediate node receives a ticket, it checks to see which links have enough bandwidth to meet the requirement. If it finds some, it then chooses a link, reserves the bandwidth and forwards the ticket on the link. If the links do not have the required bandwidth, the node reserves bandwidth along multiple links in such a way that the sum of the reserved bandwidths equals the original requirement.

In this way, the bandwidth requirement is split into sub-bandwidth requirements, equaling the bandwidths reserved along each of the links. The original ticket is split into sub-tickets, with each sub-ticket being forwarded along one of the links. Each sub-ticket is then responsible for finding a multi-path satisfying the sub-bandwidth requirement. If links cannot be found to satisfy the bandwidth requirements, the intermediate node drops the ticket. This means that links with more available bandwidth are preferred. The multi-path QoS routing algorithm is suitable for ad hoc networks with very limited bandwidth where a single path satisfying the QoS requirements is unlikely to exist.

Reference [10] proposes the protocol named QoS-TORA. It is designed to work in a TDMA network where the bandwidth of a link is measured in terms of slot reservations in the data phase of the TDMA frame. The simulation result shows considerable improvements in the probability of being able to find an end-to-end QoS path. The simulation also shows that QoS-TORA provides higher throughput under higher mobility circumstances.

INORA is a network layer QoS support mechanism mooted in [11]. It is a combination of INSIGNIA and TORA. It makes use of the INSIGNIA in-band signalling mechanism and the TORA routing protocol for MANETs. In INORA, QoS signalling is used to reserve and release resources and set up, remove and renegotiate flows in the network. These reservations can be found either in hard state or soft state. The latter is more desirable in MANETs due to its dynamic nature. The INORA protocol operates the signalling mechanism separately from the TORA routing protocol. This provides decoupling of the two mechanisms and there is no interaction between them. TORA provides the route between the source and the destination of a flow. Then the signalling mechanism INSIGNIA establishes resources for the route provided by TORA. On the other hand, INORA tries to find paths in the network that can satisfy the desired QoS requirements. In INORA, INSIGNIA asks TORA for alternative routes when the current route cannot meet the QoS requirements. The INORA scheme provides load balancing in the network, which aids in the performance of non-QoS flows.

A QoS aware routing protocol was proposed in [12]. The authors introduce the bandwidth estimation by disseminating bandwidth information through hello messages. The authors compare hello bandwidth estimation and listen bandwidth estimation methods of estimating bandwidth. These methods work equally well in static topologies by using large weight factors to reduce the congestion and minimize the chance of lost hello messages incorrectly signaling a broken route. While hello performs better in terms of end-to-end throughput, listen performs better in terms of packet delivery ratio.

B. *Power*

A Power Aware Multiple Access Protocol (PAMAS) was proposed [13]. Here, a node turns off its radio interface for a specific duration of time, when it knows that it will not be able to send and receive packets during that time because of the possibility of multiple access interference. The sleep time is of the order of packet duration, which could be very small. This approach would be quite viable for low bandwidth mobile networks, where small packets can be combined to form large packets or in radios with fast settling periods.

TABLE I. SINGLE METRIC QOS ROUTING PROTOCOLS

Metrics	Name of the protocol
Bandwidth	INSIGNIA
	CEDAR
	Bandwidth Calculation Algorithm
	OQR
	Multi-path QoS Routing Protocol
	QoS-TORA
	INORA
	QoS Aware Routing Protocol
Power	PAMAS
	CMMBCR

Conditional Max-Min Battery Capacity Routing (CMMBCR) algorithm proposed [14]. This algorithm chooses the route with minimal total transmission power if all the nodes in the route have remaining battery capacities higher than a threshold. Otherwise, routes including nodes with the lowest remaining battery capacities are avoided. This method considers both the total transmission energy utilization of routes and the residual power of nodes. When all nodes in some probable routes have enough residual battery capacity, a route with minimum total transmission power among these routes is selected. Single metric QoS routing protocols are listed in Table I.

IV. Multiple Metrics QoS Routing Protocols

A. Bandwidth and Delay

A distributed routing framework to study Delay Constrained Least Cost (DCLC) and Bandwidth Constrained Least Cost (BCLC) path problems based on selective probing is proposed [15]. While determining a QoS-aware routing path, this algorithm tries to limit the amount of flooding (routing) messages by issuing a certain amount of logical tickets. Each node maintains such end-to-end state information as delay, bandwidth and cost for every possible destination through the use of an underlying distance-vector protocol. In this method, the delay and bandwidth are used for QoS routing but not together. They are implemented as different algorithms.

This work is later extended by adopting fuzzy logic to model the imprecise state information [16]. Accordingly, a rule-based fuzzy logic control model is employed in order to determine the maximum number of probes that can be used in the feasible path discovery process between a given source-destination pair.

The basic AODV routing protocol was extended to provide QoS support in ad hoc wireless networks [17]. To provide QoS, packet formats have been modified in order to specify the service requirements, which must be met by the nodes forwarding a route request or a route reply. Several modifications have been carried out for the routing table structure and route request and route reply messages in order to support QoS routing. Each routing table entry corresponds to a different destination node. The maximum delay extension field and minimum bandwidth extension field are appended to each routing table entry. The advantage of this protocol is the simplicity of extension of the AODV protocol that can potentially enable QoS provisioning. This protocol uses delay and bandwidth as QoS parameters.

Ad hoc QoS On-demand Routing (AQOR) is a resource reservation and signaling algorithm proposed [18]. AQOR provides end-to-end QoS support in terms of bandwidth and end-to-end delay in MANETs. They introduce detailed computation algorithms for available bandwidth calculation and end-to-end delay in an unsynchronized wireless environment. It reserves bandwidth on each node, along a path that is being used by the source. AQOR offers an adaptive route recovery model when a QoS violation has been detected. This model makes the destination do a reverse route exploration. The bandwidth calculation and resource reservation model in AQOR showed promising results.

B. Delay and Energy

A new energy and delay aware protocol called Energy and Delay aware TORA (EDTORA) based on extension of Temporally Ordered Routing Protocol (TORA) proposed [19]. Energy and delay verifications of query packet have been done in each node. Simulation results show that the proposed protocol has a higher performance than TORA in terms of network lifetime, packet delivery ratio and end-to-end delay.

An energy and delay aware protocols called Energy and Delay aware Ad hoc On demand Distance Vector Routing (EDAODV) and Energy and Delay aware Dynamic Source Routing (EDDSR) based on extension of AODV and DSR proposed. Simulation results show that the proposed protocols have a better performance than AODV and DSR in terms of energy, packet delivery ratio and end-to-end delay [20].

C. Path and Energy

QoS routing for MANET using temporally ordered routing algorithm (TORA) with self-healing and optimized routing techniques (SHORT) proposed [21]. SHORT improves routing optimality by monitoring routing paths continuously and redirecting the path whenever a shortcut path is available. In this paper, the performance comparison of TORA and TORA with SHORT has been analyzed for various parameters. TORA with SHORT enhances performance of TORA in terms of throughput, packet loss, end-to-end delay, and energy. Multiple metrics QoS routing protocols are listed in Table II.

TABLE II. MULTIPLE METRICS QOS ROUTING PROTOCOLS

Metrics	Name of the protocol
Bandwidth and Delay	BCLC and DCLC
	Fuzzy Logic Model
	Extension of AODV
Delay and Energy	AQOR
	Ant-Based Multi-path Routing Protocol
	EDTORA
	EDAODV, EDDSR
Path and Energy	TORA with SHORT
Delay, Jitter and Energy	SDVR

V. QoS Routing Protocols using Optimization Techniques

The Ant colony based Routing Algorithm (ARA) proposed was suitable for MANETs is based on both swarm intelligence and ant-colony meta-heuristics [22]. ARA consists of three phases: route discovery, route maintenance, and route failure handling. In the route discovery phase, new routes between nodes are discovered with the use of forward and backward ants, similar to AntNet. Routes are maintained by subsequent data packets, i.e., as the data traverse the network, node pheromone values are modified so that their paths are reinforced.

A Genetic Algorithm (GA) based routing method for Mobile Ad hoc Networks (GAMAN) is proposed [23]. It is a source-based routing algorithm. Few nodes are involved in route computation by using small population size. The nodes in sub-population care only about the routes. The broadcast is avoided because the information is transmitted only for the nodes in a population. The GA explores different routes and they are ranked by sorting. Therefore, the first route is the best one, but other routes ranked are used as backup routes. By using a tree based GA method, the loops are avoided. This algorithm uses the delay and transmission success rate as QoS parameters.

Probabilistic Emergent Routing Algorithm (PERA) works in an on-demand way, with ants being broadcast towards the destination at the start of a data session [24]. Multiple paths are set up, but only the one with the highest pheromone value is used by data and the other paths are available for backup.

Termite is another ant-based routing algorithm that is similar to ARA proposed [25]. However, unlike the ARA, pheromone is not considered in the route discovery phase. Instead of the forward and backward ants, RREQ and RREP control packets are used to discover the routes. The RREQ packet randomly walks, not floods, through the network to discover a route to the destination. Pheromone levels are used for routing data packets and proactive seed packets are introduced for route maintenance.

An ant-based multi-path routing protocol that considers both energy and latency was proposed [26]. This paper considers mobile ad hoc networks with dual-priority traffic namely: latency-critical and not latency-critical. For latency-critical traffic, energy pheromone and delay pheromone metrics are combined after being normalized. For the latter, not latency-critical traffic, only energy pheromone metric is used.

Ad hoc Networking with Swarm Intelligence (ANSI) is a congestion-aware routing protocol, which, owing to the self-configuring mechanisms of Swarm Intelligence [27]. It is able to collect more information about the local network and make more effective routing decisions than traditional MANET protocols. ANSI is thus more responsive to topological fluctuations.

A unicast on-demand routing algorithm Swarm-based Distance Vector Routing (SDVR) is proposed to optimize three QoS parameters delay, jitter and energy [28]. This avoids the overhead of having three independent routing algorithms, one for each QoS metric. The mechanism was based on information obtained from periodically transmitted backward ANTs resulting in reinforced path-pheromone levels. The proposed protocol selects a minimum delay path with the maximum residual energy at nodes. Furthermore, the selection of QoS routes should also take into consideration the jitter metric in order to keep the minimum and maximum delay values approximate to the average delay. SDVR produced better results than the existing AODV in terms of packet delivery ratio, end-to-end delay and residual energy at node. Even though SDVR results in a slightly high routing overhead than AODV, it performs well in route discovery with dynamic changes in the network topology and produces much better throughput with very low variance in the delay.

VI. CONCLUSION

The majority of the work reported in this paper focuses on the design and performance evolution in terms of traditional matrices such as bandwidth, delay, energy (or) bandwidth and delay. QoS routing protocols are classified based on the metrics used. The concept, strengths and drawbacks of these protocols are also discussed. QoS routing protocols using optimization techniques are also described. Multimedia applications have stringent QoS requirements such as throughput, end-to-end delay, jitter and network lifetime. However, existing QoS routing solutions dealt with any one or two of the QoS parameters. To overcome this problem, new protocols that satisfies throughput, end-to-end delay, jitter and energy metrics are needed.

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