Constraint based QoS routing in MANET

[Sonika Kandari, M.K. Pandey]

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. There are many real life applications based on Quality of Service (QoS) support provided by MANETs. But QoS provisioning in MANETs is a very challenging problem when compared to wired IP networks keeping in view different constraints to be satisfied. In this paper, we reviewed the constraint based QoS routing in MANET and discussed several related issues.**

Keywords- Mobile Ad Hoc Network, 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 .The original idea of MANET started out in the early 1970s. MANET is formed by a group of nodes that can transmit and receive data and also relay data among themselves. Communication between nodes is made over wireless links.

A pair of nodes can establish a wireless link among themselves only if they are within transmission range of each other. An important feature of ad hoc networks is that route between two hosts may consists of hops through other hosts in the network [4]. When a sender node wants to communicate with a receiver node, it may happen that they are not within communication range of each other. However, they might have the chance to communicate if other hosts that lie in-between are willing to forward packets for them [5]. This characteristic of MANET is known as multihopping. QoS provisioning in MANETs is therefore a multi-faceted problem which requires the cooperation and integration of the various network layers especially for supporting real time multimedia applications.

Sonika Kandari
Research Scholar
Uttarakhand Technical University
India.

M.K.Pandey.
Director -Faculty of Computer Science & Applications.
Amrapali Institute of Management & Computer Applications
Uttarakhand Technical University
India.

II. QoS Constraints

Depending on nature of application involved, the QoS constraints could be available bandwidth, end-to-end delay, delay variance (jitter), probability of packet loss, and so on. Best QoS routing solution will be one which will guarantee QoS provisioning for QoS parameters, such as bandwidth required by the application. Let m(u, v) be the performance metric for the link (u, v) connecting node u to node v, and path $(u, u_1, u_2,\ldots, u_k, v)$ a sequence of links for the path from u to v. Three types of constraints on the path can be identified [6,7]:

A. *Additive Constraint*

A constraint is additive if

$$m(u, v) = m(u,u_1) + m(u_1,u_2) +\ldots+ m(u_k,v). \qquad (1)$$

For example, the end-to-end delay(u, v) is an additive constraint because it consists of the summation of delays for each link along the path.

B. *Multiplicative Constraint*

The A constraint is multiplicative if

$$m(u, v) = m(u,u_1) \times m(u_1,u_2) \times\ldots \times m(u_k, v). \qquad (2)$$

The probability of a packet prob(u, v), sent from a node u to reach a node v, is multiplicative, because it is the product of individual probabilities along the path.

C. *Concave Constraint*

A constraint is concave if

$$m(u,v) = \min\{m(u,u_1), m(u_1,u_2) , \ldots, m(u_k,v)\}. \qquad (3)$$

The bandwidth bw(u,v) requirement for a path between node u and v is concave. This is due to the fact that it consists of the minimum bandwidth between the links along the path.

A list of twelve combinations with multiple constraints are provided [7]. It has been proven in [8] that any multiple constraint with two or more type1 and/or type 2 constraints are NP-complete; otherwise, they are tractable. Approximation methods exist for QoS constraints that are NP-complete. Sequential filtering is commonly used approach, where multiple paths between two nodes u and v that satisfy a single metric first (like bandwidth) are found, then a subset of these paths is eliminated by optimizing over a second metric (like end-to-end delay), and so on. Table I lists vital resources which needs consideration for QoS provisioning in mobile ad hoc networks.

TABLE I. TYPICAL QOS RESOURCES

QoS Resource	*Type*	*Description*
Available link bandwidth	Concave (min/max)	This denotes that some percentage of bandwidth will be available (reserved) for QoS flows.
Link Propagation delay	Additive	Latency encountered on the network links
Delay jitter	Additive	Delay variation on the network path.
Hop count	Additive	Number of hops
Cost	Additive	Abstract measure of network resource usage.

III. Constraint Based Routing

Constraint based routing denotes a class of routing algorithm that base path selection decisions on a set of requirements or constraints, in addition to the destination. These constraints may be imposed by administrative policies or by quality of service (QoS) requirements. Constraints imposed by policies are referred to as *policy constraints*, and the associated routing is referred to as *policy routing* (or policy based routing). Constraints imposed by QoS requirements, such as bandwidth, delay or loss are referred to as *QoS constraints* and the associated routing is referred to as *QoS routing*.

In constraint based routing, two overlapping sets of routes are determined: *policy routes* and *QoS routes*. This overlap is due to the fact that some routes may conform to the underlying routing policies and also satisfy QoS requirements. QoS routing attempts to satisfy multiple QoS requirements, such as bandwidth and delay bounds. Constraints based routing (CBR) requires mechanisms for exchanging state information (eg. Resource availability) among constraint based routing processes. maintaining the state information. interacting with current intra-domain routing protocols, accommodating traffic requirements. Inputs to constraint based routing process include Traffic trunk attributes, Traffic specifications, Resource specifications and Policy specifications.

Policy routing provides many benefits, including cost savings, load balancing and basic QoS. In policy routing, routing decisions are based on several criteria beyond the destination address, such as packet size, application, protocol used and identity of end systems. *QoS routing*- selects routes based on flow QoS requirements and network resource availability. QoS routing determines feasible paths satisfying QoS requirements while optimizing resource usage and degrading gracefully during the periods of heavy load. Selected routes are typically "pinned". Table II classifies different constraint and resources for QoS provisioning.

TABLE II CONSTRAINTS AND RESOURCES CLASSIFICAITON

Constraint/ Resource	*Type*	*Description*	*Example*
Constraint	Boolean(path constrained or bounded)	Administrative constraints, bandwidth availability and delay bounds.	End-to-end delay.
Constraint	Quantitative (path optimization)	Assigns numerical values to paths so the algorithm can select among them.	highest bottleneck bandwidth among all feasible paths.
Resource	Configurable	Assigned by administrator	Link propagation delay
Resource	Dynamic	Network state dependent	Available link bandwidth
Resource	Topological	Enforced by topology of the network	Path Length

A constraint based routing process is incorporated into layer 3 (the network layer). A CBR process can be classified as offline or online based on where path computation is performed. *Single constrained vs Multi constrained QoS metrics:* Most of the protocols focus on providing an assured throughput service only, since throughput was deemed the most important requirement earlier days. These were single-constrained routing protocols.

Most of the multimedia applications require the communication to meet stringent requirements on delay, delay-jitter, cost and other QoS metrics. In this context, the trend is to move from single constrained routing to multi constrained routing. The function of multi-constrained QoS routing is to find a feasible path that satisfies multiple constraints simultaneously, which is a big challenge for MANETs where the topology may change constantly. QoS routing can be centralized, distributed, or hierarchical.

A. *Centralized Routing*

Centralized routing requires that nodes maintain global knowledge at the source. The global state has to be updated frequently to cope with network dynamics.

B. *Distributed Routing*

Distributed routing algorithms can be more scalable since path computation is divided among the nodes. Many distributed schemes make routing decisions hop-by-hop, but rely on global state for QoS routing.

C. *Hierarchical Routing*

Hierarchical routing shares advantages of both central and distributed schemes. Each node maintains partial network state. Groups of nodes are aggregated for scalability. Source routing occurs at each hierarchical level to find feasible paths, with some inaccuracy.

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IV. QoS Routing

QoS Model defines the general approach, goals and framework for providing QoS support in a network. It does not specify a particular protocol, design or implementation details. Various protocols and specifications such as QoS user interface, routing, signaling, resource reservation, error checking, measuring and correcting must work and coordinate together in a collaborative and complementary fashion in order to satisfy the QoS requirements of the underlying applications. The QoS provisioning approaches can be broadly classified into two categories, hard QoS and soft QoS approaches.

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 MANET, it is very challenging to provide hard QoS guarantees to user applications. 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. Soft QoS [9] indicates that there may be transient periods of time during which the QoS specifications are not honored. In the *fixed-level QoS*, the reservation is defined in an n-dimensional space where the coordinates define the characteristics of the service [10].

The goals of QoS routing are two fold: selecting routes with satisfied QoS requirement(s) and achieving global efficiency in resource utilization. A routing protocol for ad hoc wireless networks should have the following characteristics like it must be fully distributed, must be adaptive to frequent topology changes caused by the mobility of nodes, Route computation and maintenance must involve a minimum number of nodes. The number of packet collision must be kept to a minimum by limiting the number of broadcasts made by each node .It must optimally use scarce resources such as bandwidth, computing power, memory and battery power.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.

A. *QoS Metrics*

The following are metrics commonly used by applications to specify QoS requirements to the routing protocol: Minimum required throughput of capacity (b/s), maximum tolerable delay, maximum tolerable delay jitter and maximum tolerable Packet Loss Ratio(PLR). Consequently they may be used as constraints on route discovery and selection. Each metric is followed by a reference which provides an example of a protocol that employs the metric as a QoS constraint. Table III provides some of the metrics commonly employed by routing protocols for path evaluation and selection in order to improve all-round QoS or to meet the specific requirements of application data sessions.

TABLE III. QOS METRICS

Layer	***Metrics***
Network Layer	Achievable throughput or residual capacity(b/s)or “ available bandwidth” is the achievable data throughput of a path or node.
	End –to-end delay: the measured end–to-end delay on a path *(Additive metric)*
	Node buffer space: the number of packets in a node’s transmission buffer
	Delay jitter or variance- the measured delay jitter on a path
	Packet Loss Ratio (PLR)- the percentage of total packets sent, which is not received by the transport or higher layer agent at the packet’s final destination node.
	Energy expended per packet
	Route lifetime depends on mobility as well as node battery charge
Link and MAC Layer	MAC Delay- the time taken to transmit a packet between tow nodes in a contention-based MAC
	Link reliability or frame delivery ratio- the statistically calculated chance of a packet or frame being transmitted over a link and correctly decoded at the receiver.
	Link stability- the predicted lifetime of a link
	Node relative mobility/stability- can be measured as ratio of number of neighbours that change over a fixed period to the number that remain the same.
Physical Layer	Signal-to-interference ratio(SIR)- routing metric that shows link quality via cross-layer communication.
	Bit Error Rate(BER) –determines the number of retransmissions required over a “link”.
	Node residual battery charge
	Signal-to-interference ratio (SIR)- routing metric that shows link quality via cross-layer communication.

B. *Clustering*

A successful approach for dealing with the maintenance of mobile ad hoc networks is by partitioning the network into clusters. In this way network becomes more manageable. Clustering is a method which aggregates nodes into groups [11]. These groups are contained by the network and they are known as clusters.

C. *Network Resource Utilization*

Networking resource utilization for effective QoS routing protocol is essential hence factors like node computing time, node battery charge, node buffer space and channel capacity should be taken cared of while implementing any QoS solution .

D. *QoS Routing Heuristics*

The heuristics of QoS routing can be characterized by several aspects, including the metrics, type of path selection algorithm, instant of application of path selection algorithm and localization of the routing decision. Metrics for path selection determines most of other aspects.

1) Metric Ordering

Metric Ordering requires the identification of highest priority traffic and then compute the best paths for it. It is a kind of shortest-widest path and widest-shortest path algorithms. In shortest-widest path algorithms, paths with maximum available bandwidth is located. If there are paths of same available bandwidth, it would then select the path with shortest number of hops. These algorithms support load balancing, showing top performance with low network loading.

2) Sequential filtering

The network links that do not have enough available bandwidth are excluded from the network graph. The shortest path is then computed. For on-demand path computation, bandwidth value is obtained on request through resource reservation protocol. If paths are pre-computed , bandwidth ranges must be established.

3) Scheduling discipline

The complexity of route selection algorithms can be overcome by using the relationships among QoS parameters, determined by the nature of scheduling disciplines.

4) Admission Control

In some QoS architectures, the admission of new flows in the network is subject to a mechanism of admission control. Typically, the routing module can produce information about the network state which contribute to the admission control decision.

5) Control Theory approach

Control theory approach offers a successful track record in physical process control. It does not require accurate system models and utilize feedback mechanism. Performance of software services is governed by queuing dynamics which may be expressed by differential equations akin to those of physical systems.

6) Computational intelligence approach

As QoS routing for MANETs have two objectives ie. Finding routes that satisfy QoS constraints and making efficient use of limited resources. Hence the complexity involved in networks may require the considerations of multiple objectives at the same time, for the routing decisions.

E. *Mobility Models*

The performance of routing protocols could be evaluated with the imperative model that precisely represents mobile nodes (MNs) to provide realistic performance measurement. Brief description of of some mobility models are provided in Table IV.

TABLE IV. MOBILITY MODELS

Mobility Model	*Characteristics*
Random Waypoint Model [12]	It includes pause times between changes in direction and speed. A mobile node stay in one location for certain period of pause time .
Random Walk Mobility Model[13]	A Mobile Node moves from its current location to a new location by randomly choosing a direction and speed in which to travel .
Probabilistic Random Walk Model[14]	A model that utilizes a set of probabilities to determine the next position of an Mobile Node
Random Direction Mobility Model[15]	A model that forces MNs to travel to the edge of the simulation area before changing direction and speed, to overcome density waves produced by RWP.
Reference Point Group Mobility Model[16]	A group mobility model where group movements are based upon the path travelled by a logical center
Gauss Markov [17]	A model that uses one tuning parameter to vary the degree of randomness in the mobility pattern. Initially each MN is assigned a current speed and direction
Column Mobility Model[18]	A group mobility model where a set of mobile nodes form a line and are uniformly moving forward in a particular direction
Nomadic Community Mobility Model[18]	A group mobility model where a set of MNs move together from one location to another [18]
Manhattan Grid Model [19]	In this model nodes move only on predefined paths. The arguments –u and –v set the number of blocks between the paths.

V. MANET Challenges

Many areas of research in this field provide considerable challenge and potential to enhance the growth and proliferation of MANETs and their applications. These areas include power consumption, resource availability, location management, inter-layer integration of QoS services, support for heterogeneous MANETs, as well as robustness and security. Current challenges for ad hoc wireless networks include:

A. *Scalability*

Hierarchical routing tries to solve scalability problems in MANETs . The main idea is to divide the routing into different hierarchical levels, and utilize different routing approaches between the levels. Because of the scalability issues, most approaches have been on distributed admission control.

B. *Integration*

QoS routing can benefit a lot from efficient support of resource management and allocation at the MAC layer. Interpretation of network information like loss and delay or to send explicit status messages in the network are needed keeping in view of frequent topology changes and consequent changes in traffic pattern. Admission Control and QoS routing are also tightly connected with resource reservation. Bandwidth is widely used as metric for QoS routing, alone or associated with other metrics, such as delay and number of hops. QoS support for Multicast operations is also essential**.**

C. *Power Control*

Power control can effectively reduce interference between neighboring nodes and increase network throughput. The selection of QoS routes should also take into consideration the residual energy at nodes in order to balance the energy depletion among nodes and therefore prolong the network operational time.

D. *Admission control*

Important mechanisms for QoS provisioning are admission control and congestion control. The admission control restricts the amount of traffic in the network. Only flows with requirements that do not degrade the service of existing traffic are admitted into the network. In some QoS architectures, the admission of new flows in the network is subject to a mechanism of admission control. This mechanism interacts closely with routing. Admission control module can produce information useful for path computation subject to QoS constraints.

E. *Routing stability*

The usage of single shortest path may induce instability under heavy loads or bursty traffic. When congestion increases in one path, all traffic tends to shift to another path, with lower load. In the next iteration of path computation algorithm, the inverse path change may occur, creating oscillations. Oscillations originate network instability and contribute to congestion under dynamic routing protocols, since there is need to distribute the updates corresponding to the state change of the network.

F. *Scheduling disciplines*

Weighted Fair Queuing (WFQ) scheduling mechanism is a rate proportional scheduling discipline that isolates each guaranteed session from the others, and that has delay bounds that can be mathematically determined. In this case, queuing delay and jitter are determined by the bandwidth to reserve traffic characteristics, and buffer size is determined by bandwidth to reserve and hop count.

G. *Security*

Due to the broadcast nature of the wireless medium, communication through a wireless channel is highly insecure. MANETs are susceptible to attacks such as eavesdropping, spoofing, denial of service, message distortion, and impersonation. Without sophisticated security mechanisms, it is very difficult to provide secure communication guarantees.

H. *Traffic Classes*

Traffic engineering is important for optimizing network performance by QoS guarantees, optimization of network resources and very fast re-routing around failed paths. It encloses three levels of action: network planning, capacity management and traffic management. Constraint based routing is a powerful tool for traffic engineering at the traffic management module, since paths are selected according to the availability of network resources, using QoS routing protocols, and also subject to politics constraints, as for instance is the case of pricing

VI. 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. QoS routing approaches proposed in literature, focus on different QoS metrics. But no particular protocol provides overall solution. Some open issues which still need to be addressed are: QoS metric selection and cost function design , multi-class traffic, scheduling mechanism at source, packet prioritization for control messages, QoS routing that allows preemption, integration/coordination with MAC layer and heterogeneous networks, node location determination, Internet gateway discovery, configuration schemes for MANET node and handoff style. Continued growth is expected in this area of research in order to develop, test and implement the critical building blocks to provide efficient and seamless communications in mobile ad hoc networks. Cross layer designs will play an essential role in providing the required support mechanisms.

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About Author (s):