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A QUALITY OF SERVICE ARCHITECTURE FOR RESOURCE PROVISIONING AND RATE CONTROL IN MOBILE AD HOC NETWORKS

S.Venkatasubramanian[1] and Dr.N.P.Gopalan[2]

[1] Department of Computer Science & Engineering, Saranathan College of Engineering,
Panjapur, Tiruchirapalli, Tamilnadu, India
vsgomes@rediffmail.com
[2] Department of Computer Applications, National Institute of Technology,
Tiruchirapalli, Tamilnadu, India
gopalan@nitt.edu

ABSTRACT

Prioritized flow control is a type of QoS provisioning in which each class is provided a different QoS by assigning priority to one class over another in terms of allocating resources. It is an effective means to provide service differentiation to different class of service in mobile ad hoc networks. So the objective is to achieve a desired level of service to high-priority flows so that the wireless medium is completely utilized using adaptive rate control. In this paper, we propose to design QoS architecture for Bandwidth Management and Rate Control in MANET. Our proposed QoS architecture contains an adaptive bandwidth management technique which measures the available bandwidth at each node in real-time and it is then propagated on demand by the QoS routing protocol. The source nodes perform call admission control for different priority of flows based on the bandwidth information provided by the QoS routing. The network bandwidth utilization is monitored continuously and network congestion is detected in advance. Then a rate control mechanism is used to regulate best-effort traffic.

KEYWORDS

QoS, DRQOS, Rate control, multipath routing,

1. INTRODUCTION

A mobile ad hoc network includes a group of wireless nodes which develops a network without the deployment of existing network infrastructure. A node can communicate with the other nodes by multi-hop, when the nodes cooperate to forward packets with each other. In MANETs, the design of a Quality of Service (QoS) routing protocol is more difficult than the conventional networks because the host mobility can cause frequently unpredictable topology changes [1]. Since the last decade, MANETS are under the focus of the research community. It supports a variety of services by forming an infrastructure-less network immediately. Initially, MANETs are proposed for the emergency situations such as natural disasters, military conflicts, medical facilities etc but nowadays it is required to support the increasing demand for multimedia communications. Due to high rate requirements and severe delay constraints, maintaining real-time media traffics such as audio and video in presence of dynamic network topology is difficult [2].

There are two solutions for QoS provisioning on the Internet such as [3] such as Integrated Services (IntServ) and Differentiated Services (DiffServ). The objective of the Integrated Services (Intserv) is to provide applications with a guaranteed share of bandwidth. The requested

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QoS for a flow is either fully granted or rejected because the Intserv operates on a per-flow basis.

- **Guaranteed Services:** It provides an assured amount of bandwidth, strict end-to-end delay bounds, and minimal queuing delay to packets
- **Controlled Load Services:** It gives a service that is as close as possible to a best-effort service in a lightly loaded network and
- **Best Effort Services:** It is characterized by the absence of a QoS specification.

The first two service classes use parameters, such as token bucket rate and size, peak data rate, and minimum and maximum packet size. The routers are able to produce detailed reservations with the detailed information provided by these services about the intended packet stream.

DiffServ is a lightweight model and it is significantly proposed for the interior (core network) routers because the individual state flows are aggregated into a set of flows. It is not necessary to maintain the flow states within the core of the network because the service differentiation depends upon the per hop behaviors. Simplicity, efficiency and scalability are the advantages of the DiffServ. Hence this model can be a promising QoS model for MANETs. However, the DiffServ architecture should be suitably adapted such that it can be applied to the features of MANETs [3].

Generally, the existing solutions for QoS provisioning in MANETs can be classified into two categories [3] namely stateful approach based on resource reservation. Eg: INSIGNIA [13] and stateless approach which do not rely on resource reservation, and try to provide a certain degree of service differentiation. Eg: SWAN [14].

1.2 Priority of Traffic

Generally in QoS provisioning, the bandwidth is allocated first to the higher priority traffic in preference and then allocated to the lower priority traffic. The lower priority traffic can utilize the bandwidth only after the utilization of the higher priority traffic. If a high priority flow's traffic pattern satisfies the behavior described in the service agreement, its packets should be delivered in preference to other packets with lower priorities. On the other hand, flows with lower priorities should use as much bandwidth as possible after the transmission requirements of higher priority flows have been satisfied [6].

1.3 Rate Control in MANET

Since the available bandwidth of the wireless channel is variable and unpredictable, rate control becomes more complicated in MANETs than in the wired networks. When a source-based admission control mechanism uses rate measurements from aggregated real-time traffic as feedback, a rate control mechanism uses the per-hop MAC delay measurements from packet transmissions as feedback [4].

The rate control of TCP and UDP best effort traffic is performed locally at every mobile node in a fully distributed and decentralized manner to make sure that the bandwidth and delay requirements of real-time UDP traffic are met. In order to restrict the best effort traffic to produce the essential bandwidth required for supporting real time traffic, rate control is designed. It can also be used to allow the best effort traffic to efficiently utilize the bandwidth which is not currently utilized by the real-time traffic at any particular moment. In order to reduce the excessive delays, the total rate of all best effort and real-time traffic transported over each load shared media channel is maintained below a particular threshold rate [4].

1.4 QoS Provisioning Challenges in MANETs

Due to several problems, QoS provisioning in MANETs is much complicated when compared to wired networks. The following are some of the main QoS provisioning and maintenance problems in MANETs.

- ✓ It requires knowledge of the available bandwidth, which is difficult to be accurately estimated in a dynamic environment.
- ✓ Bandwidth reservation has to be made through negotiation between neighbors within two to three hops other than only the direct neighbors sharing the same channel, and this needs signaling message exchanges between them. Moreover, when the neighbor moves out of the reservation area of the node, the reserved bandwidth in a neighbor should be released through some mechanism. Hence, an extra control overhead will be introduced by these signaling messages and consumes limited bandwidth and energy.
- ✓ The reserved bandwidth over the entire duration of an active session cannot be guaranteed. Some of the reserved bandwidth might be stolen by the oncoming node, if a communicating node moves towards a node which has reserved some bandwidth for flow(s). The reserved bandwidth over the link between them might be unavailable or the link might be broken, if two nodes on the end of a link move away from each other.
- ✓ In MANETs, due to the dynamic topology, there is no clear definition of what is core, ingress or egress router. Since all the nodes in the network cooperate to provide services, there is no clear definition of a Service Level Agreement (SLA). On the other hand, an infrastructured network where the services to the users in the network are provisioned by one or more service providers [3].
- ✓ Since the wireless bandwidth and capacity in MANETs are affected by interference, noise and multi-path fading, it is limited and the channel is not reliable. Moreover, the available bandwidth at a node cannot be estimated exactly because it involves in a large variations based on the mobility of the node and other wireless device transmitting in the vicinity etc [5].

In this paper, we propose to design a QoS architecture for resource provisioning and rate control of various traffic classes.

2. RELATED WORK

R. Gunasekaran et al [7] have proposed a model called High-Privileged and Low-Privileged Architecture (HPLP) for the forthcoming Ad Hoc networks where the differentiated services can be achieved for different classes of users. They have considered only the bandwidth reservation among the various factors influencing the differentiated services and identified the different factors that can influence the efficiency of the bandwidth reservation.

Claude Chaudet et al, [8] have proposed a distributed algorithm to allocate bandwidth to each mobile according to the topology of the network and the available bandwidth on each mobile for stable ad hoc networks. Their algorithm guarantees a non null minimum bandwidth to each mobile. With their algorithm, each mobile computes its bandwidth usage in order to avoid saturating its capacity or its neighbors and congestion is less likely to appear in the network.

M. Mirhakkak et al [9] have developed a prototype implementation of resource reservation, running as an extension to the Reservation Setup Protocol (RSVP) protocol. Their approach is to expand the semantics of the reservation, so that, instead of being a single value indicating the level of service needed by an application, it becomes a range of service levels in which the application can operate, together with the current reserved value within that range.

Kumar Manoj et al [10] have proposed a bandwidth control management (BWCM) model to improve the QoS performance by minimized end-to-end delay. In addition to end-to-end delay, they have proposed an algorithm for end-to-end bandwidth calculation and allocation. They have considered different QoS traffic flows in the network to evaluate the performance of their proposed algorithm of BWCM model. Their algorithm includes a set of mechanisms: control management, co-ordination temporary resource reservation process.

Belkadi Malika et al [11] have proposed a new solution combining QoS (Quality of Service) routing protocol and flow control mechanism. This QoS routing protocol selects the routes with more resources in an intelligent manner rather than diffusion. It returns the best route offering a higher transmission rate, a less delay and a more stability. Their protocol uses a new metric to compute the most stable route. To reinforce the congestion avoidance, they have added a flow control mechanism to adjust the sender's transmission rate for each route.

Marek Hejmo et al [12] have proposed a distributed QoS signaling protocol which is an extension to the SWAN protocol. Their proposed DoS-resistant QoS (DRQoS) signaling scheme employs distributed rate control to manage the bandwidth resources of the network, but does not rely on the maintenance of per-flow state. Their signaling protocol provides QoS for real-time traffic and employs mechanisms at the medium access control (MAC) layer, which serve to avoid potential attacks on network resource usage. Their proposed signaling scheme achieves a compromise between signaling protocols that require the maintenance of per-flow state and those that are completely stateless.

3. PROPOSED QOS ARCHITECTURE

3.1 Overview of the Architecture

In this paper, we propose to design a QoS architecture which has four basic components:

- Adaptive Bandwidth Management
- QoS Routing
- Call Admission Control
- Rate Control.

The adaptive bandwidth management measures the available bandwidth at each node in real-time. This bandwidth information is then propagated pro-actively or retrieved on demand by the scalable QoS routing. The source nodes in the DiffServ model perform call admission control for real-time flows based on the bandwidth information provided by the QoS routing. The congestion control part is unique to mobile ad hoc networks. In a MANET, even though admission control is performed to guarantee enough available bandwidth before accepting any real-time flow, the network can still experience congestion due to mobility or connectivity changes. Thus, the fourth component, congestion control, is extremely important to our QoS architecture. It monitors the network bandwidth utilization continuously and detects network congestion in advance with the help of the adaptive bandwidth management component. A rate control is then used to regulate best-effort traffic and ensure that best-effort traffic coexist well with real-time traffic.

3.2 Adaptive Bandwidth Management

In our QoS architecture, each node will continuously estimate its available bandwidth. The bandwidth information will then be used for QoS capable routing protocols to provide support to admission control.

We compute the available bandwidth based on the channel status of the radio to determine the busy and idle periods of the share wireless media. By examining the channel usage of a node, we are able to take into account the activities of both the node itself and its surrounding neighbors and therefore obtain a good approximation of the bandwidth usage. The channel utilization ratio is defined as the fraction of time within which a node is sensing the channel as being utilized. An 802.11 wireless radio has four states:

1. Busy state (transmitting or receiving packets)
2. Carrier sensing channel busy (some other nodes within its neighborhood are transmitting packets)
3. Virtual carrier sensing busy (deferral to RTS or CTS packets)
4. Idle state (not in any of the above states).

Among the four states, the states the first three states can be treated as busy state and the fourth state as the idle state. Each node will constantly monitor the channel state changes (from busy to idle or from idle to busy) and record the time period that the radio is in each state.

For each time period *T*, we then calculate the channel utilization ratio CH_{util} as

$$CH_{util} = \frac{channel - busy - period}{T} \qquad (1)$$

To smooth the channel utilization estimation, we define a smoothing constant $\delta \in [0,1]$. Suppose the last channel utilization ratio is $CH_{util}(t-1)$ and the channel utilization ratio measured in the current sampling time window is CH_{util}. Then, the current channel utilization ratio is given as $CH_{util}(t) = \delta\ CH_{util}(t-1) + (1- \delta)\ CH_{util}$. The channel utilization ratio $CH_{util}(t)$ is bounded between 0 and 1. After correctly estimating the channel utilization at time *t*, we then are able to calculate the available bandwidth of a node at time *t* as

$$ABWt = CH_{BW}(1- CH_{util}(t)). \qquad (2)$$

Here, CH_{BW} is the raw channel bandwidth.

3.2.1 Bandwidth Reservation

In our scheme, we use a soft bandwidth reservation where each node in the network will periodically calculate its own available bandwidth, based on the bandwidth measurement technique discussed in the previous subsection. The available bandwidth calculation will be used by our call admission control component to determine if flows can be admitted for a particular service class. Once a flow is admitted and starts sending data traffic, the bandwidth resource occupied by the flow will be automatically taken into consideration during the periodic available bandwidth measurement intervals. Therefore, resource reservation is done implicitly without the need to keep track of per flow information; only per class information is needed.

3.3 QoS Routing

We use our previously designed QOS based multipath routing protocol intended for mobile ad hoc networks [15]. Enabling a QoS constrained route from source to destination is the objective of this routing protocol.

A QoS-based routing metric for MANETs should incorporate minimum available bandwidth and end-to-end latency along with congestion around a link. Congestion is related to channel quality, which depends on the MAC access contention and channel reliability. So our algorithm should rely on the following metrics to allocate weights to individual links.

- End-to-End Delay
- Channel Quality
- Link Quality

We now introduce the weight metric W which assigns a cost to each link in the network. The weight W combines the link quality Lq, channel quality C_{occ} and the average delay D_{avg} , to select maximum throughput paths, avoiding the most congested links.For an intermediate node *i* with established transmission with several of its neighbors, the W for the link from node i to a particular neighboring node is given by

$$W = Lq + C_{occ} + D_{avg} \qquad (3)$$

3.3.1 Route Request

During the route discovery phase of the protocol, each intermediate node uses an admission control scheme to check whether the flow can be accepted or not. If accepted, a Flow Table (FT) entry for that particular flow is created. The FT contains the fields Source (Src), Destination (Dst), Reserved Bandwidth (BWres), Minimum bandwidth (BWmin). Each node collects the bandwidth reserved at its one hop neighbors (piggybacked on periodic HELLO packets) and stores it in its Neighbor Table (NT) .The Neighbor Table contains fields Destination (Dst), Reserved Bandwidth (BWres), No. of Hello Packets (No Hello).

Let us consider the scenario and the route

S ------- R1------ R2 ------ R3-- ---- D

To initiate QoS-aware routing discovery, the source host S sends a RREQ. When the intermediate host R1 receives the RREQ packet, it first estimates all the metrics as described in the previous section.

The host R1 then calculates its weight W_{R1} using (3).

$$RREQ_{R1} \xRightarrow{W_{R1}} R2$$

R2 then calculates its weight W_{R2} in the same way and adds it to the weight of R1. R2 then forward the RREQ packet with this added weight.

$$RREQ_{R2} \xrightarrow{W_{R1}+W_{R2}} R3$$

Finally the RREQ reaches the destination node D with the sum of node weights

$$RREQ_{R3} \xrightarrow{W_{R1}+W_{R2}+W_{R3}} D$$

3.3.2 Route Reply

The Destination node D sends the route reply packet RREP along with the total node weight to the immediate upstream node R3.

$$RREP \xrightarrow{W_{R1}+W_{R2}+W_{R3}} R3$$

Now R3 calculates its cost C based on the information from RREP as

$$C_{R3} = (W_{R1}+W_{R2}+W_{R3}) - (W_{R1}+W_{R2}) \tag{4}$$

By proceeding in the same way, all the intermediate hosts calculate its cost.

On receiving the RREP from all the routes, the source selects the route with minimum cost value.

3.4 Call Admission Control

With the support from the above described QoS routing, the source node can then decide whether to admit a new real-time flow. This is usually referred to as call admission control (CAC). When a new request with certain bandwidth requirement comes, the source will perform admission control following the procedure described below.

- The source node first consults the local routing table. If the destination is within the local scope and the available bandwidth is enough, then the flow is accepted. If the destination is within scope, but bandwidth is not enough, then, reject the flow.

- If the destination is not within the local scope, the source node then consults the landmark routing table. It first examines whether it has enough bandwidth to the corresponding landmark node of the destination. If not enough, the flow is rejected.

- If bandwidth to the landmark node is enough, the source node then has to further check the minimal and maximal bandwidth propagated by that landmark. If the requested bandwidth is smaller than BW_{min}, the flow can be admitted. If the requested bandwidth is larger than BW_{max}, the flow is rejected.

- If, however, the requested bandwidth falls between BW_{min} and BW_{max}, the bandwidth information in the landmark routing table is not enough to make an admission decision. A probing packet is then sent by the source node to the corresponding landmark to collect the exact available bandwidth to the destination node. After getting the reply back, if the available bandwidth can meet the requirement, then accept the flow. Otherwise, the flow is rejected.

3.5 Rate Control

The Packet Generation Rate (PGR) of the low priority flow is computed at low priority source based on the formula as follows:

$$PGR_{new}^{L}(t) = \frac{1}{PGI_{new}^{L}(t)} \tag{5}$$

where $PGI_{new}^{L}(t)$ is the computed Packet Generation Interval of low priority flow L at time t given by

$$PGI_{new}^{L}(t) = (1 - \delta \times [ER_H]) \times PGI_{old}^{L}(t) \tag{6}$$

where, ER_H is the detected error in Packet Arrival Interval of high priority flow and it is given as,

$$ER_H = PAI_{Desired}^{H} - PAI_{Detected}^{H} \tag{7}$$

where, PAI is the Packet Arrival Interval, $PAI_{Desired}^{H}$ is the desired high priority Packet Arrival Interval and $PAI_{Detected}^{H}$ is the detected high priority Packet Arrival Interval. Here δ is the proportionality constant. We assume that each high priority flow has a pre-specified Packet Generation Rate which should correspond to the Packet Arrival Interval at any intermediate node when high priority flow does not have to face any contention. This value is known to every node in the network and this corresponds to the desired high priority Packet Arrival Interval.

The positive or negative adjustment required in the PGI at low priority source is a fraction of the old PGI of the low priority flow, which is proportional to the error introduced in high priority Packet Arrival Interval. On high priority flow detection, if low priority PGR is decreased, its effect on the improvement of high priority Packet Arrival Interval requires some time. Hence, taking control decision on each back propagated value of (Transmitted Packet Arrival Interval) $TPAI(s)_t^{Li}$ would be incorrect and will lead to more unnecessary oscillations of both Detected high priority Packet Arrival Interval as well as PGR of low priority flow. Hence, a window is introduced at the low priority source, which effectively stores $TPAI(s)_t^{Li}$. So, the PGR or PGI of low priority source Li is controlled with the Average of $TPAI(s)_t^{Li}$, where averaging is done on the Window-Size W. Hence, Detected Packet Arrival Interval at source S for the low priority flow Li at time t or $PAI_{Detected}^{Li}(t)$ is computed as

$$PAI_{Detected}^{Li}(t) = \frac{\sum_{j=0}^{W-1} TPAI(s)_t^{Li}}{W} \tag{8}$$

4. SIMULATION RESULTS

4.1. Simulation Model and Parameters

The Network Simulator (NS2) [16], is used to simulate the proposed architecture. In the simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. The distributed coordination function (DCF) of IEEE 802.11 is used for wireless LANs as the MAC layer protocol. It has the functionality to notify the network layer about link breakage. In the simulation, 50 mobile nodes move in a 1000 meter x 1000 meter region for 100 seconds simulation time. We assume each node moves independently with the same average speed. All nodes have the same transmission range of 250 meters. In our simulation, the speed is 10 m/s and pause time is 5 sec. The simulated traffic is Constant Bit Rate (CBR).

The simulation settings and parameters are summarized in table

No. of Nodes	**50**
Area Size	1000 X 1000
Mac	802.11
Radio Range	250m
Simulation Time	100 sec
Traffic Source	CBR
Packet Size	512
Speed	10m/s
Flows	2,4,6,8 and 10
Rate	0.5,1.0,1.5 and 2Mb

4.2 Performance Metrics

The proposed QoS Architecture for Resource Provisioning and Rate Control (QARP-RC) is compared with the DRQoS [12] scheme. The performance is evaluated mainly, according to the following metrics.

i. **Average End-to-End delay**: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.
ii. **Aggregated Throughput**: We measure aggregated throughput in terms of no. of packets received.
iii. **Fairness:** For each CBR flow, we measure the fairness as the ratio of throughput of each flow and total no. of flows.
iv. **Packet Loss**: We measure the packet loss, which is the no. of packets lost per unit time.
v. **Blocking Probability**: We measure the blocking probability as the ratio of rejected requests per total no. of requests.

4.3 Results

A. Effect of Varying Rate

In the first experiment, the transmission rate is varied as 0.5, 1.0, 1.5 and 2Mb and the above metrics are measured.

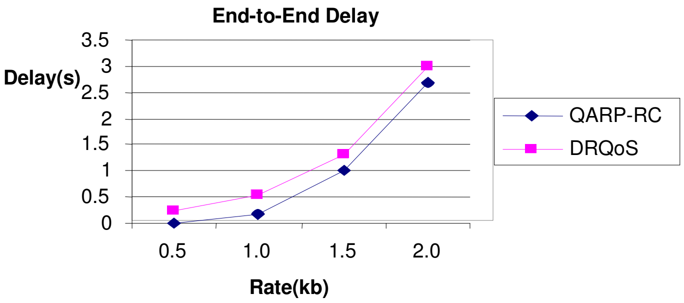


Fig.1 Rate Vs Delay

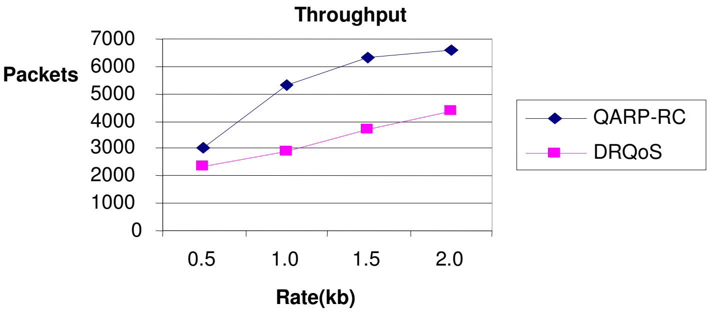


Fig.2 Rate Vs Throughput

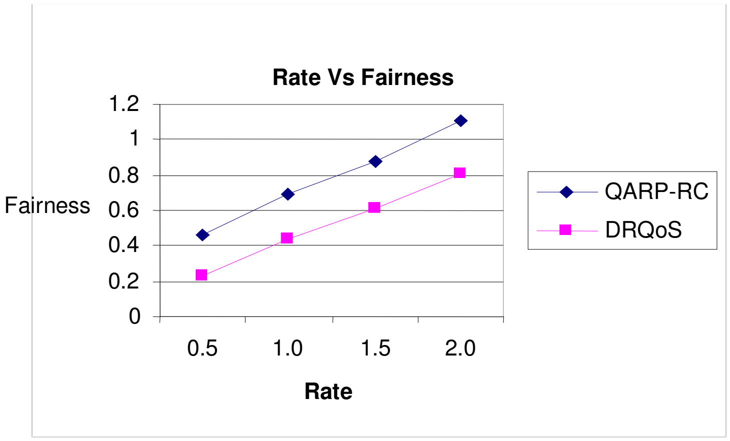


Fig.3 Rate Vs Fairness

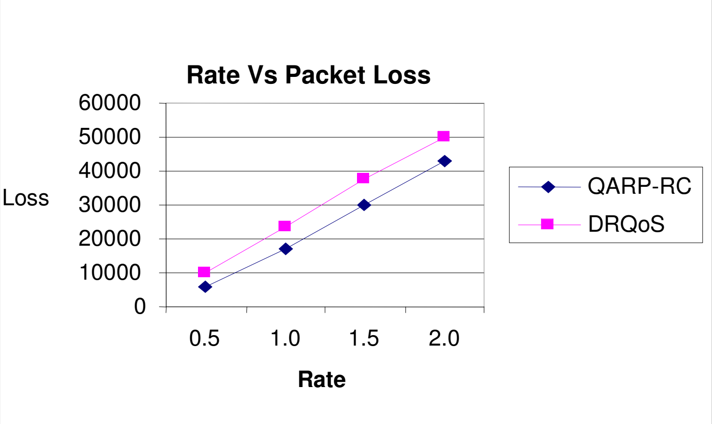


Fig.4 Rate Vs Packets Loss

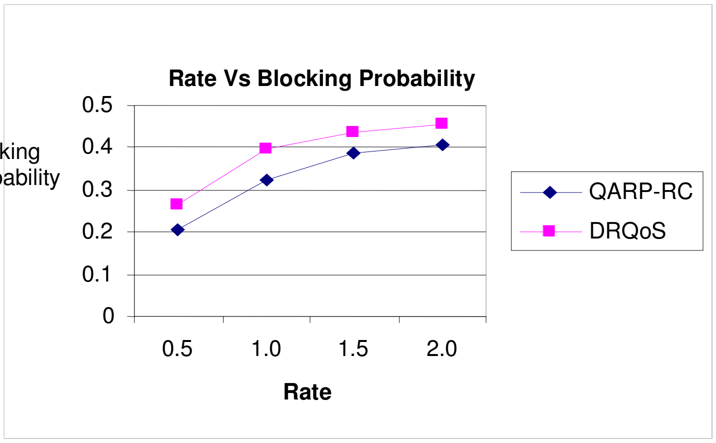


Fig.5 Rate Vs Blocking Probability

Fig 1 shows the end-to-end delay values when the rate is increased. It is clear that QARP-RC has less delay when compared to DRQoS, since it has the QoS routing protocol which selects best path. Fig 2 and 3 show the result of throughput and fairness when the rate is increased. From the figures, it can be seen that the throughput and fairness are more in the case of QARP-RC scheme than DRQoS, because of the adaptive bandwidth management and rate control schemes of OQARP-RC. Fig. 4 presents the packets loss for both the schemes. Because of QoS routing and rate control policies, QARP-RC has less packet loss than DRQoS.Fig.5 shows the blocking probability when the rate is increased. From the figure it is clear that QARP-RC attains less blocking probability than the DRQoS, since it has the effective call admission control mechanism.

B. Effect of Varying Flows

In the second experiment, we vary the number of data flows as 2,4,6,8 and10.

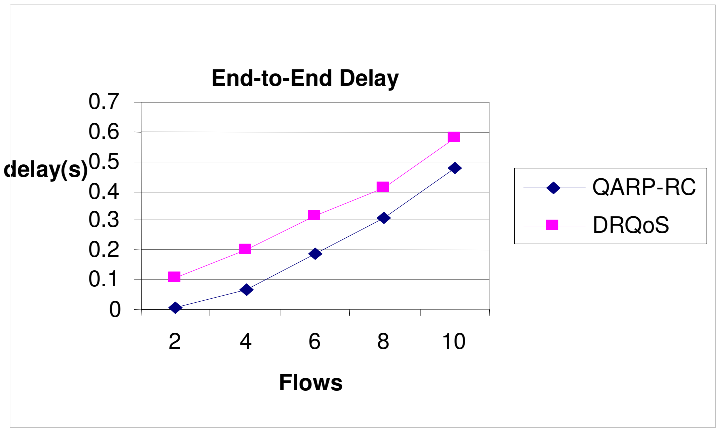


Fig.6 Flow Vs End-to-End delay

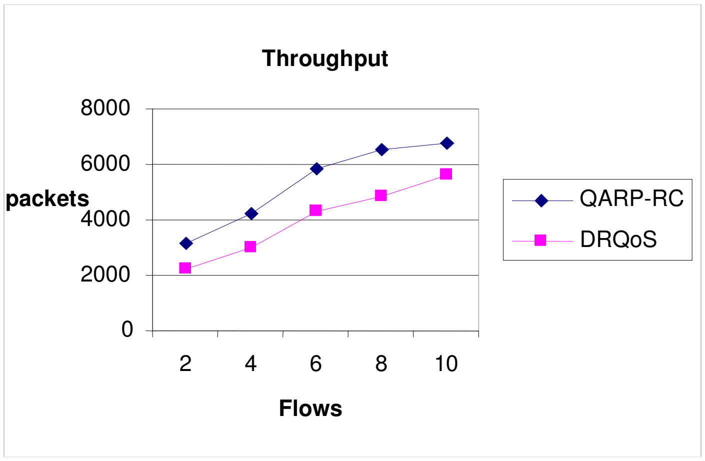


Fig.7 Flow Vs Throughput

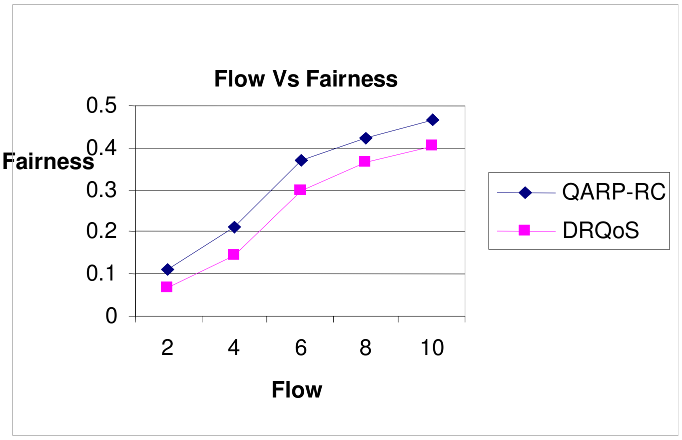


Fig.8 Flow Vs Fairness

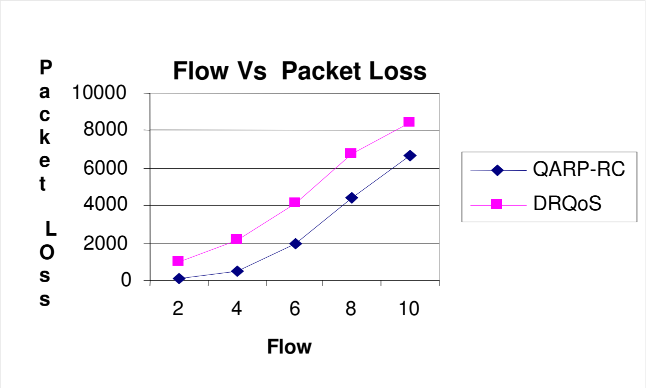
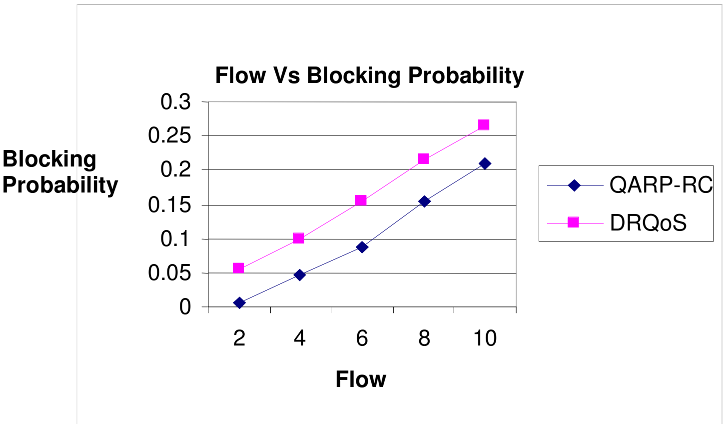


Fig.9 Flow Vs packet Loss



When the flows are increased, the cumulative delay is increased. Fig. 6 shows the end-to-end delay values when the flow is increased. It is clear that QARP-RC has less delay when compared to DRQoS, since it has the QoS routing protocol which selects best path. Fig. 7 and 8 show the result of throughput and fairness when the flows are increased. From the figures, it can be seen that the throughput and fairness are more in the case of QARP-RC scheme outperforming DRQoS, because of the adaptive bandwidth management and rate control schemes of OQARP-RC.Fig. 9 presents the packets loss for both the schemes. Because of the QoS routing and rate control policies, QARP-RC has less packet loss than DRQoS.

When the flows are increased, the resulting blocking probability is also increased. Fig.10 shows the blocking probability when the flow is increased. From the figure it is clear that QARP-RC attains less blocking probability than the DRQoS, since it has the effective call admission control mechanism.

5. CONCLUSION

In this paper, we propose to design QoS architecture for Bandwidth Management and Rate Control in MANETs. In our QoS architecture, each node will continuously estimate its available bandwidth. The bandwidth information will then be used for QoS capable routing protocols to provide support to admission control. For this, we have used our previous Robust Multipath Routing (QRMR) protocol. It allocates weights to individual links on the basis of the metrics link quality, channel quality and end-to-end delay. The traffic is balanced and the network capacity is improved as the weight value assists the routing protocol to evade routing traffic through congested area. The source nodes then perform call admission control for different priority of flows based on the bandwidth information provided by the QoS routing. In addition to this, a rate control mechanism is used to regulate best-effort traffic, whenever network congestion is detected. In this mechanism, the packet generation rate of the low-priority traffic is adjusted to incorporate the high-priority traffic.

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Authors

S.Venkatasubramanian received the B.E. degree in Electronics and Communication from Bharathidasan University and M.E. degree in Computer science from Regional Engineering College. He has 14 years of teaching experience. He is currently pursuing doctoral research in mobile Ad hoc networks. His areas of interest include mobile networks, Network Security and software Engineering. He has published two papers in the international journals. At present he is working as Associate Professor in Department of CSE at Saranathan college of Engineering, Trichy, India.

Dr.N.P.Gopalan is a Professor in the Department of computer application at National Institute of Technology, Tiruchirapalli. He received the M.E. degree in Computer science from Regional Engineering College. and Ph.D degree in theoretical computing from Indian Institute of Science .He has more than 30 years of teaching experience. He has published more than 20 papers in International, National journals, conference proceedings and 3 books. His areas of research include Data mining, Web Technology, Distributed Computing, and Theoretical Computer Science.