Cross-Layer proposal for QoS Routing in Mobile Ad-Hoc Networks

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Abstract— **Mobile ad hoc networks require a complex management to efficiently exploit the networks resources also covering the heavily demanded QoS constraints in current multimedia applications. This paper presents a cross-layer design that tries to combine the functionality of the Routing layer with Medium Access Control (MAC) information and physical layer parameters to provide the routing algorithm with the more accurate information about the environment. Thanks to this knowledge, it is feasible to estimate the current status of the links in the available paths, in order to find the more stable one that is able to guarantee the QoS requirements during the whole connection. The cross-layer design of the proposed routing algorithm in conjunction with an effective resource allocation in the MAC layer operates as a distributed admission control which is able to improve the global performance in the network.**

Key words: QoS Routing, cross-layer, ad-hoc networks

1. INTRODUCTION

The high development that mobile communications networks and the provided services have experienced in the last few years has supposed a great scientific and technical effort in order to support Quality of Service mechanisms for mobile users. In the case of mobile ad hoc networks (MANETs) this effort is even more noticeable due to the complexity of the dynamic environment of these networks. In order to facilitate QoS support in MANETs, it is very important to solve the tradeoff between guaranteeing the requirements for the QoS provision with the best efficiency in the use of the networks resources. In order to provide quality delivery for QoS demanding applications several QoS Routing approaches [1] – [4] have been proposed, but it is still a challenging task. This paper presents a cross-layer design that tries to combine the functionality of the Routing layer with Medium Access Control information and physical layer parameters to provide the routing algorithm with the more accurate information about the environment. Thanks to this knowledge, it is feasible to estimate the current status of the links in the available paths, in order to find the more stable one that is able to guarantee the QoS requirements during the whole connection. In addition, a proper resource sharing is even more important when considering mixed offered traffic. If QoS guarantees are demanded for certain connections, some kind of distributed admission control (CAC) must be able to allocate resources for them at the expense of other less QoS constrained connections, without disrupting the already QoS active ones.

The cross-layer design of the proposed QoS routing algorithm in conjunction with an effective resource allocation in the MAC layer operates as a distributed CAC which is able to improve the global performance in the network.

2. THE QOS ROUTING ALGORITHM

2.1. QoS Routing Protocol

The activation of a QoS application is considered as a flow that needs a stable route during the duration of the whole connection. In the simple Ad hoc On-Demand Distance Vector Routing (AODV [5]) operation the source broadcasts *requests packets* (*RREQ*) referring this flow and each intermediate node rebroadcasts the first received copy of the *RREQ* until it reaches the destination, which sends a *reply message* (*RREP*) along the reverse path to the source. In terms of quality of service, several paths can satisfy the QoS requirements and the first *request packet* that reaches the destination does not actually identify the best path. The trade-off between delay and other QoS requirements makes it difficult to choose the best solution. However, we can try to find a suboptimum path in terms of access delay but better satisfying the QoS requirements.

The proposed QoS routing algorithm is a modified version of the Ad hoc On-demand Multipath Distance Vector Routing (AOMDV) protocol [6] which works in conjunction with a MAC TDMA layer (ADHOC MAC [7]) in a cross-layer operation. This algorithm takes advantage of multipath routing to find several alternative paths, although only the best one is selected according certain QoS metric based in the bandwidth requirements, and maintained for that flow. The operation of the proposed solution acts as a distributed admission control performed during the discovery process of the routing protocol since it finds the best route for a new connection guaranteeing its bandwidth demands without interfering in the already accepted connections. In addition, the interaction with the MAC layer provides a distributed scheduling and reservation mechanism as well as a service differentiation that allow to carry out an appropriate resource management improving not only the individual connections but also the global network performance.

2.2. ADHOC MAC Protocol

Determining the bandwidth availability in an ad-hoc environment is not an easy task and it is basically dependent on the current MAC layer. Moreover, an effective MAC scheme for ad hoc networks should be able to provide reliable communication services and to implement solid resource management schemes in order to match different QoS demands. In this proposal, a MAC TDMA layer based in the

ADHOCM MAC protocol has been considered. ADHOC MAC works on a slot synchronous physical layer and implements a completely distributed access technique capable of dynamically establishing a reliable single-hop Basic broadcast CHannel (BCH) for each active terminal, i.e., each transmission within a BCH is correctly received by all the terminals within the transmission range of the transmitter. Each BCH carries signaling information that provides a prompt and reliable distribution of layer-two connectivity information to all the terminals.

In this work, the proposed QoS Routing algorithm interacts with the MAC layer in order to perform a distributed admission control and scheduling as well an on-demand reservation mechanism that allows to efficiently allocate resources for QoS differentiated communications. To this purpose, the access and reservation strategies proposed in [10] have been considered in order to provide a reservation based mechanism to handle the access to data user resources and a simple but efficient traffic differentiation by exploiting the in band signaling provided by the ADHOC MAC protocol. The basis of this strategy relies on the use of the BCH capabilities to signal the request before the access, in such a way that collisions can be theoretically avoided (Book In Advance Strategy – BIAS). A terminal can receive several requests for a given resource and not all of them have to be destined to the terminal itself. Upon all the received requests, it has to decide what to signal next according to them as well as its own information about the resource status. The decision must be consistent with the rest of neighbors. Upon the basis of this access scheme, information related to the priority can be also included in the BCH in order to manage connections with different QoS requirements. In this case, the requests can be differentiated according to given priorities access. First, it has to choose with the same rule as without priorities within the set of requests of high priority and just if there are not high priority requests, choose among the low ones. Pre-emption can be carried out in order to allocate resources for high priority services despite the lower ones. The policy used to resolve the conflicts in reservation is explained in detail in [10].

2.3. QoS metric

2.3.1. Path Bandwidth calculation process

The AOMDV routing protocol has been improved using a path bandwidth calculation algorithm based on [3] to measure the available bandwidth considering the whole path. The basic idea of this algorithm is to find the available TDMA slots that can be used for transmitting in every link along the path avoiding hidden and exposed terminal problems [8] so that these slots, if reserved, will be interference-free. Therefore future collisions and break links can be reduced. The cross-layer implementation of the routing algorithm allows to take the particular MAC layer into account to find these available slots. The measurement is performed and updated in each node during the discovery phase. The path bandwidth calculation ends in the destination node, and the calculated value represents the maximum available bandwidth between the source and the destination. A function of the ratio between the demanded and this available bandwidth expresses the quality of the path, identified through a QoS metric. The destination node, which waits for receiving *RREQ*s from different nodes, uses this metric to classify the alternative paths, then sending a *RREP* only through the best selected one (higher QoS metric).

The basis of the path bandwidth algorithm is explained in [3], although some slight modifications have been introduced. The actual implementation operates as explained next.

According to the MAC level information, a node k is aware of the available slots for transmitting without interfering other connections (SRT_k set) and the available ones for receiving without collision (SRR_k set). The ADHOC MAC protocol includes the capability of using priorities to give QoS at the MAC level. When resources of high priority are demanded, it is able to preempt low priority reservations if needed. Taking this into account the set of available slots for the new QoS flow in the routing level will include these slots as available. High priority reservations are protected from preemption. During the path bandwidth calculation and the *RREQ*s propagation in the discovery phase, the set of available slots for communication in link *(i,j)* is calculated in node *j* and denoted as PB_{ij}. Avoiding hidden and exposed terminals to have interference-free communications requires the set of transmitting slots to be disjointed in three consecutive hops. According to this rule, each intermediate node appends its own SRT to the *RREQ* packet but also the PBij calculated in the previous two hops. With this information, in addition to the SRR, the next node receiving this *RREQ* can calculate again the sets of slots to made them disjointed to the new link and update the appended information before forwarding the *RREQ*. The number of available slots in each set is reduced to the minimum value in the three hops used to compute them. When the destination node receives the *RREQ*, the dimension of the last availability set determines the total available bandwidth in the path. If it matches the requirements, it will be considered to be compared according to its metric in the final decision.

Once a path is selected, the destination node sends the *RREP* packet through the reverse path to the source. The more updated information of the actual available set in every link will be in the 3 hops downstream neighbor, according to the path bandwidth calculation process. Therefore, to have an updated version of the available slots, during the reply phase a node sends back the more updated ones it has (these ones it had calculated before and the new updated received from its neighbor), appending this information to the *RREP*. When a node receives a *RREP*, it updates the sets to be forwarded but also select the effective slots to transmit, according to the demands, from the available set in the corresponding link. Fig. 1, schematically explains the whole process.

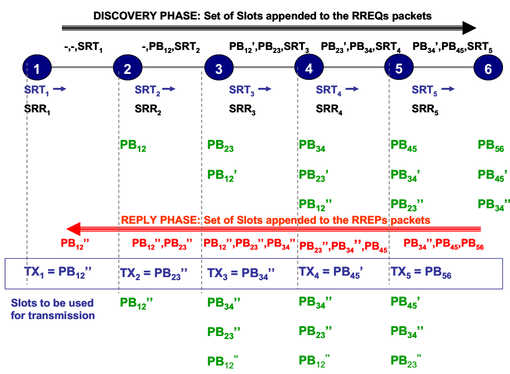

Figure 1: Example of Path Bandwidth calculation.

When an intermediate node receives a *RREQ* for a new flow, it updates a QoS metric (1) – (2), appended in the *RREQ*, and evaluates if the QoS requirements are met. Only those packets received from paths with a valid metric are forwarded. Repeated *RREQ*s are no directly dropped in the destination node in order to perform a multipath operation so that several paths can be discovered and finally one can be selected.

$$BW_{metric,RREQ} = \begin{cases} 0.5 \cdot N_{av,link} / N_{RREQ} & N_{av,link} < N_{RREQ} \\ 0.5 \cdot \left(1 + N_{av,link} / N_{\max,link}\right) & otherwise \end{cases} \quad (1)$$

$$BW_{metric,PATH} = \min\left(BW_{metric,RREQ}\right) \quad (2)$$

$BW_{metric,RREQ}$ is the BW value measured in the previous link where $N_{av,link}$ is the number of available slots in that link and N_{RREQ} is the number of slots that matches the demanded bandwidth. $N_{max,link}$ is the maximum number of slots that could be theoretically available, according to the path-bandwidth calculation algorithm. $BW_{metric,PATH}$ is the more restricted value in the path, equal to the last link BW_{metric}, as it is shown in [3]

2.3.2. *Race condition and parallel reservations*

Some of the problems that arise when reserving resources during the on-demand routing process in an ad-hoc network are the race condition and the parallel reservations problem as described in [9]. The race condition occurs when multiple reservations happen simultaneously at an intermediate node, and parallel reservations arise when two parallel paths are being reserved without common intermediate nodes, but when two or more of this nodes are 1-hop neighbors. Fig.2 and Fig.3 shows some examples. When the reservation has not been performed yet, for example, during the discovery phase, and no additional considerations about these effects are taken into account, a node can select the same available slots for different connections, so it will collide in the future and one or even all of them will be blocked due to transmission failures although an available path had been founded.

In [9] some solutions are proposed, but the basis of them is the assumption of a forward selection, that is, the specific set of demanded slots are selected in the discovery process and labeled as allocated resources, not reserved yet, until the reply phase. These allocated resources are also announced in the neighborhood, so that nor a neighbor neither this node will try to select them for a parallel connection.

In the routing proposal that is explained in this paper, during the discovery phase every intermediate node evaluates which are the total available resources when it receives a *RREQ* packet and, in the end, the final value (Path Bandwidth) is used as a measurement of the quality of this particular path (QoS metric). The one to be actually reserved is chosen in the destination node according to the highest metric. Therefore, a node cannot label any slot as allocated in this discovery phase. On the contrary, it must consider the same amount of available slots for new connections being discovered at the same time to allow the different *request packets* to reach its destination nodes, or the best path may not be selected. This operation not only allows to calculate the QoS metric but also makes the resources allocation more flexible, since a premature selection of transmitting slots without taking into account the whole path can lead to a wrong selection and a future blocked connection.

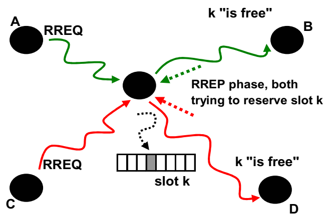

Figure 2: Race condition.

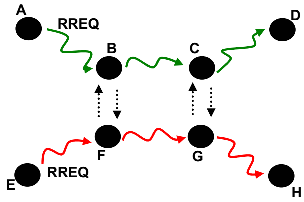

Figure 3: Parallel reservations.

In this case, the race condition and parallel transmission problems are noticeable in the reply phase, when a node selects the effective slots for transmitting, since if the sets of available slots are dealt independently for the different connections, it can choose the same resources for more than one connection. In order to partially solve this problem, in this paper we adapt the ideas proposed in [9] to the considered implementation of the protocol. The basic operation of the protocol is to select these slots but to wait for receiving data packets of this connection to actually reserve the resources. The probability of simultaneous selection for the same slots increases with the time that nodes are waiting for reservation. However, although a node cannot consider as allocated the resources in the discovery phase, it is possible to do it in the reply phase. Allocation (according to the ADHOC MAC protocol) and later reservation is performed at this time, so a node can avoid to select these slots to a new connection. In addition, during the booking phase and when the reservation is made, the neighborhood becomes aware of these high priority slots, thanks to the FI transmission in the BCH, even before the *reply* reaches the source node and this begins to send packets. Therefore, the period when nodes do not know its neighbors reservation is reduced as well as the blocking probability.

2.4. QoS Monitoring

Once a path is selected according to its metric, the variability in the network conditions would make infeasible to maintain this path without a mechanism of QoS monitoring and path updates. In the normal operation of the routing protocol nodes react to broken links sending error messages to inform the neighborhood about this event. New discoveries arise, as soon as the involved nodes realize the phenomenon, but this mechanism only alerts about "broken links", assuming the path is unviable, whereas in a "QoS environment" links can be still viable although the bandwidth is not enough for covering the QoS demands of a specific connection.

The proposed QoS Routing performs an updating process using certain routing information piggybacked in the DATA-ACK packets, similar to that sent during de *RREQ-RREP* phase which allows to realize if the QoS constrains are not met anymore, so the source of the connection can try to rediscover the path.

3. PERFORMANCE EVALUATION

In order to evaluate the performance of the routing protocol, we have built up an event driven simulator in C++ which implements the functionalities of the proposed cross-layer design, considering the ADHOC MAC protocol interacting with the modified AOMDV, including the path-bandwidth calculation algorithm integrated in the routing process. The simulator functionalities allow to emulate a realistic ad-hoc environment, with a transmission range fixed to 500 m, considering a transmitted power of 20 dBm, and a Kammerman propagation model. As first step of analysis, we simplify the physical layer assuming neither fading nor shadowing in the calculation of the received power. The connectivity among terminals is simply determined by the Euclidean distances. As consequence, a transmission can be erred due to collisions only.

Results have been obtained considering static conditions, considering a topology configured with 25 terminals randomly positioned within a square area with edge equal to 2 Km and CBR traffic sources (64 and 128 kbps – 2 and 4 TDMA slots). The MAC radio frame subdivision [10] consists of 25 BCH slots and 50 slots for additional data user communications. In order to evaluate the proposed QoS Routing, the measured parameters are delay of correctly received packets and throughput, calculated as the ratio among dispatched and offered traffic expressed in packets.

The proposed QoS Routing has the facility of dealing with connections as best effort traffic (BE Routing) or considering them as QoS flows (QoS Routing). In addition, the possibility of selecting the best effort routing for a connection that has been blocked as a QoS flow (QoSBE Routing) has been implemented. The basic operation of the protocol, without taking into account the race condition and parallel reservations problems is denoted as BASIC MODE. The modifications on the normal operation to reduce the consequences of these problems, which is based on considering the allocated slots as reserved to avoid future reutilization is named the FULL MODE. Simulations results conclude that the FULL MODE outperforms the BASIC one, as it is shown in Fig. 4. The improvement is more relevant at higher offered traffic since the probability of simultaneous connections rises. In this case, with the FULL MODE operation there are less blocked connections due to a better scheduling, so the total amount of packets received is higher. In the remaining of the simulations, the QoS Routing operations is FULL MODE.

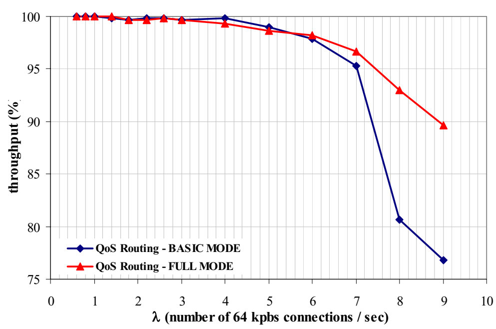

Figure 4: Throughput for connections of 64 kpbs. Operation of QoS Routing in BASIC and FULL MODE

Fig.5. compares the different routing strategies (BE, QoS and QoSBE) with the same offered traffic. The QoS Routing strategy allows to better allocate the resources admitting only the connections that have found the required slots during the discovery phase. Although in the best effort strategy all the connections are dispatched, since there is not actually enough resources, congestion forces to discard packets then reducing the total throughput as well as increasing the delay, as it is shown in Fig. 6.

Fig. 7 shows that the blocking probability in the QoS Routing operation becomes the probability of being made best effort in the QoSBE Routing. With the highest offered traffic, it is even higher than the former blocking probability, because the additional best effort traffic which is scheduled less efficiently makes it more difficult to allocate in the best way the QoS flows. Depending on the QoS constraints, the QoSBE strategy can be useful to dispatch more connections, or the QoS one may be preferred to ensure highest throughput and lower delay to the admitted connections.

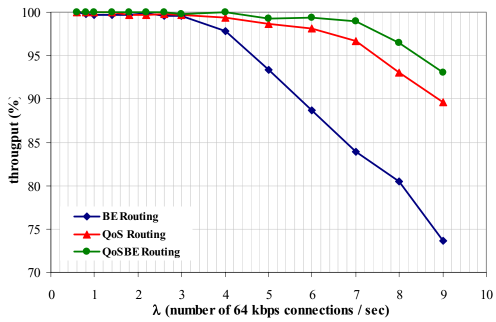

Figure 5: Throughput for connections of 64 kpbs. BE, QoS and QoSBE Routing strategies.

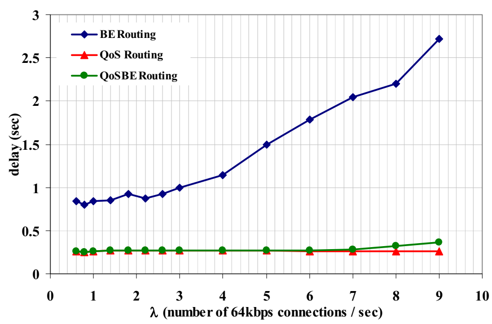

Figure 6: Mean Packet Delay for connections of 64 kpbs. BE, QoS and QoSBE Routing strategies.

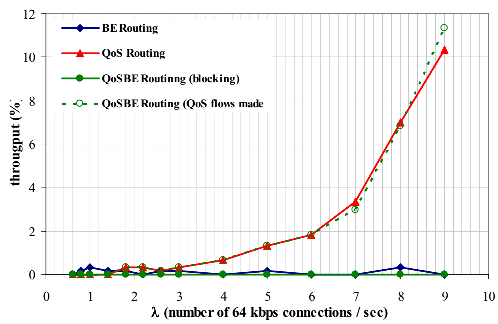

Figure 7: Blocking probability for connections of 64 kpbs. BE, QoS and QoSBE Routing strategies.

The QoS Routing performance depends on the demanded bandwidth of the QoS flows. Considering the same value of offered traffic in terms of the demanded MAC resources, the higher the bandwidth, the lower the number of connections with more slots to be allocated. Fig. 8 shows that the obtained throughput is lower with higher demands (128 kbps). Since a connection needs to be allocated more resources in each link of its path, with a best effort routing strategy the discarding policy due to congestion reduces the throughput. The same offered traffic for 64 kbps implies the same resources to be distributed among the different links of the different paths reducing congestion. The situation is analogous with the QoS Routing, but in this case, the distributed scheduling only allocates connections if there is available resources. The blocking probability is higher for 128 kbps connections since it is more difficult to allocate a higher bandwidth in a lower number of paths than a lower one but distributed among different paths.

Fig. 9 shows the throughput obtained with the QoS Routing for a mixed traffic scenario, where QoS flows compete with Best Effort traffic for resources. Dotted and dashed lines refer to throughput of QoS flows and BE connections respectively. In this case, we can observe not only the ability of the distributed admission control to allocate the QoS flows despite the best effort connections, but also the higher performances they experience, thanks to the QoS also offered by the MAC layer by using this level priorities.

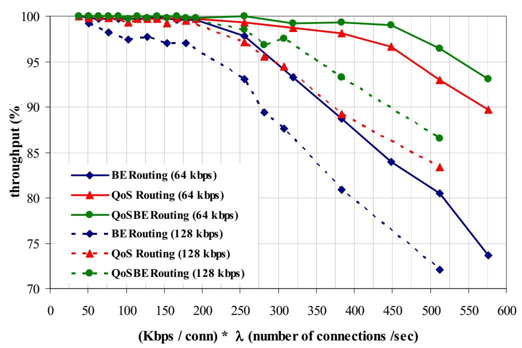

Figure 8: Throughput for connections of 64 kpbs and 128 kbps. BE, QoS and QoSBE Routing strategies.

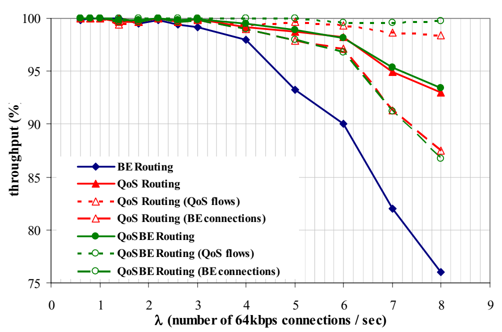

Figure 9: Throughput for connections of 64 kpbs (%50 QoS flows, 50% BE connections). BE, QoS and QoSBE Routing strategies.

4. CONCLUSIONS

This paper presents a cross-layer proposal for QoS Routing in order to guarantee bandwidth requirements in ad-hoc networks. The joint operation of the AOMDV routing protocol with the ADHOC MAC protocol in addition to a path bandwidth calculation algorithm works as a distributed admission control that allows to flexibly allocate resources for bandwidth demanding connections. The total amount of offered traffic that can be effectively scheduled is increased in front of a best effort strategy, although some of the connections can be blocked. However, this blocking probability implies in fact a reduction on the congestion of the network which allows to deal better with the admitted connections, which experience higher individual throughput and lower delay.

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