A novel QoS framework for medium-sized MANETs supporting multipath routing protocols[*]

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Abstract

Multipath routing protocols have proved to be able to enhance the performance of MANET in terms of reliability, load balancing, multimedia streaming, security, etc. However, deploying a QoS framework on top of such routing protocols is a complex task, requiring an appropriate QoS strategy to be developed and deployed. In this paper we propose such a strategy, validating it through simulation. The results achieved show that the proposed QoS framework can perfectly coexist with multipath routing protocols, achieving significant improvements on the overall network performance, especially from the point of view of demanding applications.

1 Introduction

A Mobile Ad-hoc Network (MANET) is composed by a group of stations that communicate wirelessly with each other to form a network. These networks do not require any sort of infrastructure for support. Two of the most important factors that characterize MANETs are the routing protocol and the wireless technology employed by the stations that conform it. When referring to wireless technology we mean the combination of the physical and MAC layers.

The IEEE 802.11 standard [1] was created to provide wireless local area networks (WLANs) to different environments, such as public access networks, enterprise networks, home networks, etc. It operates in free bands such as the industrial, scientific and medical (ISM) band at 2.4 GHz or the unlicensed 5 GHz band. The IEEE 802.11e [8] task group has recently finished some extensions to the IEEE 802.11 standard to provide QoS at the MAC level.

The availability of a wireless technology that offers QoS support is one of the most important requirements to deploy a QoS framework in MANET environments. By enabling traffic differentiation at the MAC level, it is possible to design a strategy built on top of the IEEE 802.11e technology that can successfully support traffic with QoS constraints.

Concerning QoS frameworks in MANET environments, we can find in the literature some interesting proposals. Examples of such proposals are INSIGNIA [11] and SWAN [7]. Both proposals attempt to offer a solution that resembles the Integrated Services and Differentiated Services Internet QoS models, respectively. They offer a complete framework for QoS in MANETs using single path routing protocols. To the best of our knowledge, though, there haven't been yet any proposals of complete QoS frameworks for MANETs that can operate adequately with both single path and multipath routing protocols, irrespectively of what routing protocol is actually being used. Also, none of the previous proposals was designed specifically for the IEEE 802.11e technology.

In this work we propose a solution called Distributed Admission Control for Manet Environments (DACME). DACME aims at small/average sized MANETs, and the purpose is to offer QoS communication among peers. In the design of DACME we combined the IEEE 802.11e technology with probe-based admission control to achieve a novel framework for QoS support in MANETs. The implementation and deployment of DACME in real-life MANETs is effective, simple, and without strong requirements on intermediate stations participating on traffic forwarding tasks. The aim is also of supporting multipath routing protocols automatically; this means that DACME agents should operate without being aware of the routing protocol being used. At the same time, they must follow a strategy that can be deployed over both single path and multipath routing protocols without performance penalties or any other sort of

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[*] This work was supported by the *Ministerio de Educación y Ciencia* under grants TIN2005-07705-C02-01 and TIC2003-00339.

QoS-related problems.

The rest of this paper is organized as follows: in the next section we refer to the multipath routing protocol that will be used to validate DACME in multipath routing environments. In section 3 we expose the core of our proposal (DACME). In section 4 we present some performance results and finally, in section 5, some conclusions will be drawn, along with references to future work.

2 MDSR: a multipath extension of DSR

In a previous work [2] we proposed an extension to the Dynamic Source Routing protocol (DSR) [6] to improve the performance of multimedia traffic in environments characterized by high levels of mobility. Basically, we extend DSR's route discovery mechanism to increase the average number of routes found per node. Our technique consists of allowing a node to propagate a second route request (RREQ) message if the route included is node disjoint relatively to the first one.

The RREQ initiator, upon receiving multiple replies, will update its route cache and use them to do per-packet traffic splitting through two alternative disjoint paths whenever possible. Experimental analysis shows that splitting traffic through two different link-disjoint paths is enough to counter the effects of mobility on multimedia traffic and to improve load balancing, while maintaining a low routing overhead (see [2] for more details).

The multipath routing protocol described in this section, referred from now on as MDSR (Multipath-DSR), will be used to validate DACME by allowing us to assess if DACME does not misbehave when coexisting with a multipath routing protocol.

3 The distributed admission control mechanism

In terms of QoS provisioning, the multipath routing strategy presented before could cause several problems and misbehavior if it is not taken into consideration by admission control algorithms. First, since traffic from an application will traverse distinct MANET regions, the congestion encountered might be different. This means that measurements concerning available bandwidth and end-to-end delay are not easy to obtain. Second, a QoS algorithm that performs some sort of resource reservation or assessment by sending a packet from source to destination (e.g. SWAN or INSIGNIA) will act only upon one of the paths used; that path will then be loaded well below reservation levels because only part of the traffic will go through that path; the other paths used will receive the rest of the traffic and, due to a lack of previous reservation, are prone to be overloaded. Another problem that may occur is that the same reservation is performed on both paths (or more, if applicable) locking resources unnecessarily, or that nodes on the alternate path start dropping QoS-demanding packets.

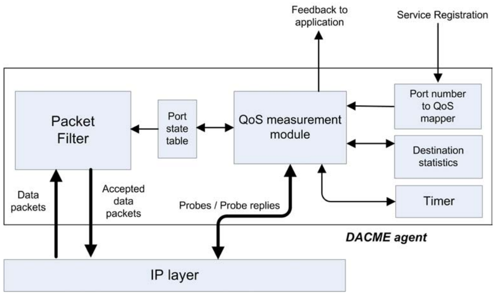

Figure 1. Functional block diagram of the DACME agent

The admission control mechanism we propose only requires two DACME agents, one running at the source and the other at the destination node. Both agents communicate in order to assess the current state of the path, and decide when a connection should be accepted, maintained or rejected. Such agents do not require any intervention from the intermediate nodes, besides the obvious task of forwarding probe packets as if they were data packets. Actual QoS support is achieved by configuring the IP TOS (Type of Service) packet header field according to the desired QoS. The IEEE 802.11e MAC must then map the service type defined in the IP TOS header field to one of the four MAC Access Categories available (see [8]).

In figure 1 we present the functional blocks diagram of a DACME agent. An application that wishes to benefit from DACME must register with the DACME agent by indicating the source and destination UDP port numbers, the destination IP address and the required QoS parameters; these data are stored internally in a table indexed using source port numbers.

The *QoS measurement module* will perform path probing according to the services that have registered with DACME. The destination agent, upon receiving probe packets, will update the *Destination statistics* table where it keeps per source information of packets received during the current probe. After receiving the last packet of a probe (or if a timeout is triggered) the destination agent will send a reply back to the source DACME agent. The *QoS measurement module*, upon receiving each probe reply, will update the state of the path accordingly. Once enough information is gathered, it checks all the registered connections towards that destination, updating the *Port state table* accordingly (with either accept or drop). If only part of the registered connections can be accepted, preference is given to those which have registered first. This module can then notify applications of QoS variations by means of using a callback function is requested at service registration.

Relatively to the probing process, DACME sources are configured to send ten back-to-back packets to the destination per probe. According to the analysis performed in [4], this value offers a good trade-off between accuracy and overhead. We set the probe packets to the Video Access category independently of the type of service registered by the application. This way we avoid that a higher priority connection (e.g. voice) causes the degradation of an on-going connection with lower priority (e.g. video) if both connections are generated by the same user, therefore sharing the same terminal; this interaction among traffic of different priorities is also known as the *stolen bandwidth problem* [10].

Each source agent keeps a timer to be able to react in case a probe reply is never received. So, after sending a probe, it sets the timer to go off after 500 ms; we consider this value adequate for small/medium-sized MANETs because it is the one used by both DSR and MDSR routing protocols when waiting for replies to a route discovery request. If no probe reply is received, causing the timer to be triggered, or in the case that the probing process is completed, the source will schedule a new probing cycle after 3 seconds ±500ms of jitter to avoid possible negative effects due to probe synchronization. This value was chosen from the "Hello"-based version of AODV [5], where the authors determine that a reaction time of 3 seconds is adequate in the presence of typical topology change rates; moreover, we consider that it offers a balance between the performance drop caused by poor reaction times and the overhead introduced by the probing process itself.

The DACME agent in the destination, upon receiving the probe, will obtain a measure of available end-to-end bandwidth; that value is then returned to the source. The DACME source agent, when receiving the probe reply packet, will collect the $B_{measured}$ values sent by the destination agent to reach a decision on whether to admit the connection or not. In [4] we found that the mean value for $B_{measured}$ is a biased estimator that over-estimates available bandwidth. Therefore, the source agent must correct the bandwidth estimation value to adjust the short term measurements of DACME to the long term measurements obtained using actual traffic. Taking into account the need to correct the bandwidth deviation, we now propose a strategy to perform probabilistic admission control. Such strategy is the one described in algorithm 1.

Algorithm 1 Probabilistic admission control mechanism

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After receiving a probe reply do {
  correct the bandwidth estimation using all available values
  if (there is a level of confidence of 95% that the available bandwidth is higher that the requested one)
    then accept the connection
  else if (there is a level of confidence of 95% that the available bandwidth is lower that the requested one)
    then drop the connection
  else if (number of probes used is less than maximum allowed)
    then send a new probe
  else maintain the previous path state }
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This algorithm allows reducing the number of probes required to take a decision to a value as low as two probes; such a fast decision occurs often in those situations where it quickly becomes evident that the available bandwidth is either much higher or much lower than the requested one. The maximum number of probes allowed per cycle is set to five, according to the analysis performed in [4]. If, after sending five probes, still no decision can be reached, we maintain the previous path state; that way, if a connection is waiting for admission it will remain blocked, and if it is active it will remain active. Such criteria aims at increasing the stability of the system.

It should be noticed that the DACME agent or the application itself should always avoid occupying all the available bandwidth to cope with network bandwidth fluctuations, routing data and probes from other sources. This issue will be addressed in the next section.

4 DACME performance with DSR and MDSR in MANETs

In this section we evaluate the effectiveness of our proposal using simulation. Experiments are conducted using the ns-2 [9] discrete event simulator. All simulations are carried out in a typical MANET environment sized 1900x400 squared meters with 50 nodes. The choice of the scenario aims simultaneously at avoiding network partitioning and increasing the average number of hops. Nodes are moving at a constant speed of 5 m/s according to the random waypoint mobility model. Concerning the nodes' radio interfaces, these are IEEE 802.11g/e enabled.

Relatively to the radio range, it is of 250 meters, leading to an average of 4 hops between nodes. With this setting we consider that the routing protocols are conveniently stressed, causing a significative number of path changes throughout simulations.

Concerning traffic, we have four background sources whose purpose is to allow varying the amount of background congestion in the network. These sources generate negative-exponentially distributed traffic in the *Video*, *Best Effort* and *Background* Access Categories. The traffic share for each Access Category is: 50% for the Video AC and 25% for both Best Effort and Background ACs. We do not generate background traffic for the Voice AC because it was designed to support low data-rate streams such as voice streams; moreover, we want to avoid provoking routing misbehavior since routing traffic is also set to the Voice AC (see [3] for more details on this problem).

Concerning the data sources under study (regulated by

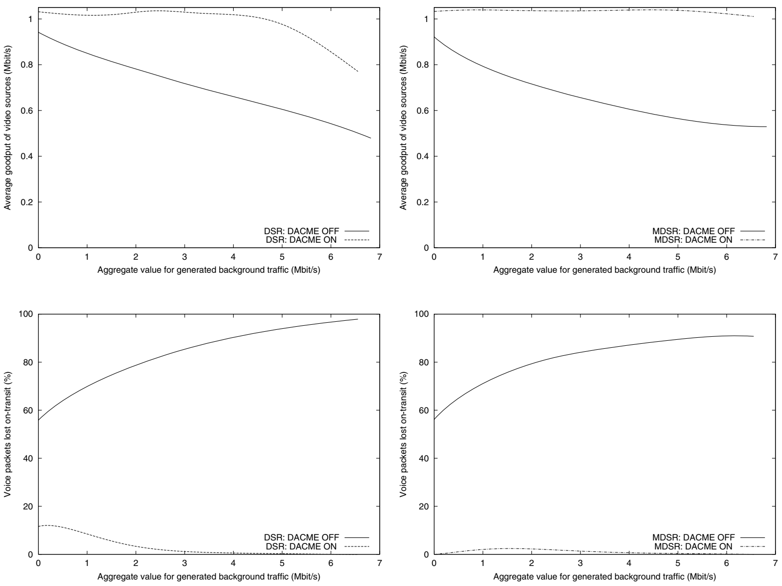

Figure 2. Improvements on video goodput (top) and voice packet drops (bottom) by using DACME with DSR (left) and MDSR (right)

DACME), these consist of four video streams and three voice streams. The video sources send CBR traffic at 1 Mbit/s using 512 byte packets. Voice sources are VoIP streams simulated using a Pareto On/Off distribution with both burst and idle time set to 500 ms. The shaping factor used is 1.5, and the average data rate is of 100 kbit/s. As mentioned in the previous section, we should avoid occupying all the available bandwidth, and so we must also set the minimum amount of bandwidth that is reserved for routing traffic and DACME probes from the different sources; for the routing protocols under study (DSR and MDSR) we found through simulation that this extra bandwidth should be above 0.75 Mbit/s to achieve a good performance; in this work the chosen value was of 1.25 Mbit/s.

Relatively to start and end times for the different sources, the first video source is started at the beginning of the simulation, and then every 15 seconds a new data source becomes active, alternating between voice and video sources. Each source is active for two minutes, and all results presented are average values over 10 simulation runs.

Figure 2 shows the improvements in terms of video goodput and voice packets dropped by using DACME. We observe that, when DACME is not used, the average goodput for the different video sources drops steadily with increasing congestion. By using DACME the average goodput values are maintained much higher for both DSR and MDSR; in fact, we verify that when DACME is active MDSR performs even better than DSR, which is a strong indicator that the admission control strategy adopted for DACME can operate in conjunction with multipath routing protocols. Relatively to the improvements introduced by DACME, these occur because sources are only allowed to transmit if the DACME agent finds the available bandwidth to be enough.

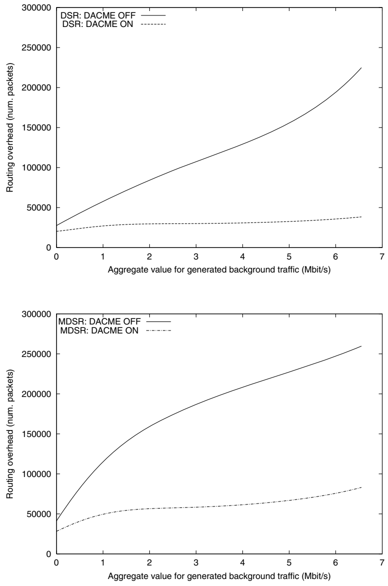

Figure 4. Routing overhead for DSR (top) and MDSR (bottom)

From figure 2 we can also observe that, by using DACME, the number of voice packets lost is greatly reduced. Again the combination of MDSR and DACME is the best one, achieving a very low packet loss rate always.

We now proceed to evaluate the performance achieved in

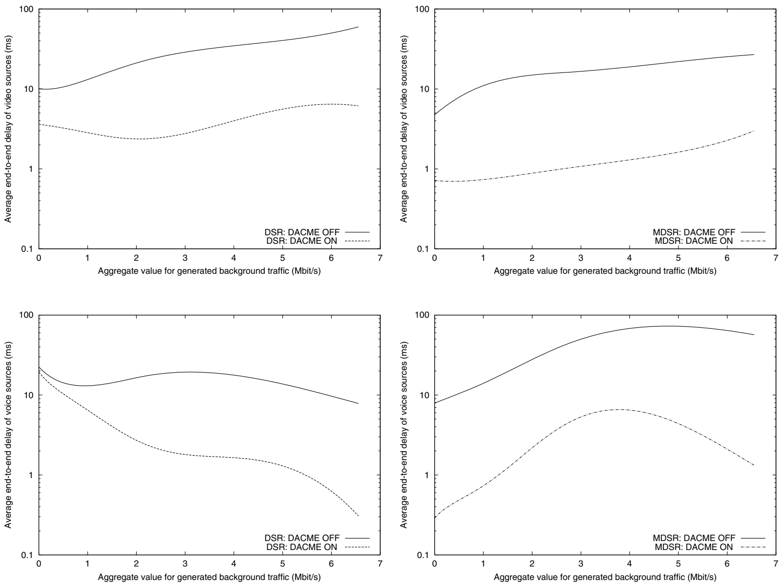

Figure 3. Average end-to-end delay values for video (top) and voice (bottom) sources for DSR (left) and MDSR (right)

terms of end-to-end delay. The results are shown in figure 3. Under these conditions we see that, by using DACME, the end-to-end delay values for video and voice sources were lower with both DSR and MDSR. In terms of video traffic, it is interesting to notice that MDSR performs better than DSR with and without DACME; this shows that the traffic splitting strategy used in MDSR offers advantages in terms of end-to-end delay despite the fact that sometimes part of the traffic traverses paths with more hops. Concerning voice traffic, the end-to-end delay results also show that both DSR and MDSR clearly benefit from DACME. The difference of curve shapes between DSR and MDSR is related to the degree of voice traffic accepted into the network, and to contention between data packets and routing packets.

One of the main differences between DSR and MDSR is related to the amount of routing overhead generated. MDSR's route discovery mechanism and, to a lesser extent, traffic splitting through different routes results in an increased routing overhead. Hence, we expect to observe this difference when analyzing the routing overhead generated in our experiments. In figure 4 we show the variation in terms of total routing packets when varying the amount of generated background traffic. We observe that MDSR does in fact generate a higher amount of routing traffic than DSR with or without DACME. However, it is important to notice that, by using DACME, we are able to maintain the routing overhead stable when congestion increases, avoiding the routing misbehavior problem we discussed in [3].

Two issues that deserve further attention are: the acceptance rate experienced by DACME-regulated traffic, and the relative channel occupation. Relatively to the former, voice sources generate much lower data rates, and so we expect the amount of voice traffic admitted into the MANET to be higher than the amount of video traffic. In figure 5 we show the differences between both when using either DSR or MDSR. We can see that, effectively, higher-rate video sources are more penalized by congestion, experiencing more frequent cut-offs than voice traffic which is less bandwidth demanding.

In terms of channel occupation, we find that using DACME does not promote a poor usage of radio resources; in fact we find that, as the number of QoS sources increases, the relative channel usage also increases. In our experiments we were able to improve the relative channel occupation by up to 80% when compared to a non-DACME solution; this upper limit was achieved during the period when all QoS sources are active.

The results found in this section lead us to conclude that using DACME can clearly avoid wasting resources by interrupting communication when the minimum QoS requirements are not met. Comparing DSR to MDSR we observe that the effect they have on QoS streams differs; yet, we can definitely affirm that the proposed admission control mechanism is adequate for using in conjunction with both single path and multipath routing protocols.

5 Conclusions and future work

In this paper we presented a novel QoS framework for MANET environments based on the use of the IEEE 802.11e technology along with our novel admission con-

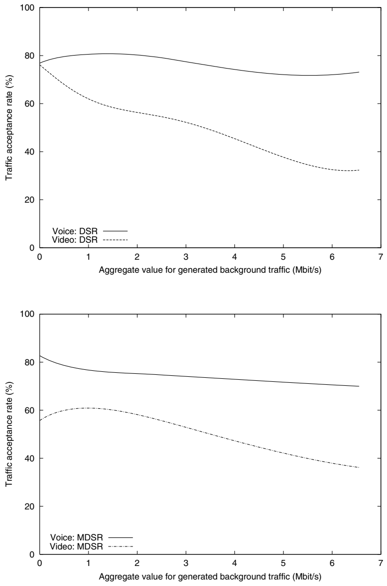

Figure 5. Percentage of admitted traffic using both DACME versions at different congestion levels for DSR (top) and MDSR (bottom)

trol system for MANETs (DACME). Contrarily to previous proposals in this field, our solution imposes very few requirements on MANET nodes. In fact, MANET stations only require IEEE 802.11e capable interfaces and to handle packets according to the TOS field in their IP header. Our strategy avoids burdening intermediate stations with bandwidth measurements, resource reservations and maintenance, probe processing, traffic shaping and policing, etc., allowing any station conforming the MANET to participate on admission control tasks without being aware of it.

One of the main issues addressed in this work was related to providing an admission control strategy that could operate with single path as well as with multipath routing protocols. With this purpose we described an extension to the DSR routing protocol which enhances the route discovery algorithm to find more node disjoint paths, and that was also capable of doing per-packet traffic splitting. We then described the general functionality of the distributed admission control mechanism proposed, evidencing its relation with the different protocol layers in a TCP/IP network.

Using simulation we compared the performance of DSR and its multipath-enabled version (MDSR) in a typical MANET environment, showing that DACME is very effective in enhancing the QoS experienced by video and voice data streams. We also proved that DACME perfectly adapts to multipath routing protocols, with simulation results showing that most times an inferior performance of MDSR compared to DSR was converted into a superior performance simply by introducing DACME in the system.

As future work we plan to evaluate the effectiveness of DACME in real-life testbeds by developing a prototype for GNU/Linux operating systems.

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