Using distributed admission control to support multimedia applications in MANET environments*

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Abstract

MANET environments suffer from changing connectivity conditions and radio contention among stations that conform it. Despite the several on-going endeavors, no simple and effective solution has yet been offered that can be easily deployed and cope with real-life environments and restrictions. In this work we present a distributed admission control mechanism for MANETs called DACME that combines the use of probes with the emerging IEEE 802.11e technology. We show that with DACME we can greatly improve the support of multimedia applications in MANETs with little overhead.

1 Introduction

Mobile Ad-hoc Networks consist of several independent mobile terminals that cooperate with each other to create a network of stations. Such networks do not require the presence of any sort of infrastructure, being particularly useful in military and rescue scenarios. In MANETs all stations must be constantly adapting to varying link quality towards their neighbors, and also to changes in network topology (routing related adaptation). In such environments it is extremely hard to achieve reliable communication between two hosts, and the situation becomes even more complex if some of the sources generate traffic with QoS requirements.

In the past there have been some proposals aiming at setting a framework for QoS support in MANET environments. Examples of such proposals are FQMM [7], INSIGNIA [12] and SWAN [5].

FQMM [7] has been presented as a flexible QoS model for MANETs. It proposes a hybrid per-flow and per-class QoS provisioning scheme, so that traffic of the highest priority benefits from per-flow QoS provisioning, while other category classes are given per-class QoS provisioning; the IEEE 802.11 MAC layer is used without changes. In a later work [6], though, the authors discovered that the proposed priority buffer and scheduling schemes fail when UDP traffic has higher priority than TCP.

Lee et al. [12] proposed INSIGNIA, an in-band signaling system that supports fast reservation, restoration and adaptation algorithms. With INSIGNIA all flows require admission control, resource reservation and maintenance at all intermediate stations between source and destination to provide end-to-end quality of service support. However, Georgiadis et al. [11] show that link interferences (due to the hidden terminal problem) in multihop wireless networks make the problem of selecting a path satisfying bandwidth requirements an NP-complete problem, even under simplified rules for bandwidth reservation.

Ahn et al. [5] designed SWAN, a stateless network model that provides service differentiation in MANETs. One of the main advantages of SWAN is that is does not require the support of a QoS-capable MAC to provide service differentiation; instead, it uses plain IEEE 802.11. SWAN's admission control mechanism requires all stations to keep track of the MAC's transmission delay of all packets in order to estimate available bandwidth; such estimation, though, can be incorrect for several reasons. An IEEE 802.11 radio performs adaptive rate control when transmitting data according to the Signal-to-Noise Ratio (SNR) towards the receiving station. Moreover, stations may dynamically select different RTS/CTS and fragmentation thresholds. Therefore, the association of a global estimate for transmission delay with a certain bandwidth in the link towards a specific target station becomes unclear, especially in real implementations.

In a previous work [1] we analyzed the performance of IEEE 802.11e [8] in MANET environments, concluding that with an appropriate admission control mechanism, such technology would be able to offer good QoS support in envi-

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ronments with distributed channel access such as MANETs.

In this work we propose a solution which we named Distributed Admission Control for Manet Environments (DACME). DACME offers a new framework for QoS support in MANETs based on the IEEE 802.11e technology. The purpose of DACME is offering a distributed admission control mechanism whose implementation and deployment in real-life MANETs is effective, simple, and without constraints or strong requirements on intermediate stations participating on traffic forwarding tasks. The aim is also of supporting multipath routing protocols and adaptive multimedia applications.

The rest of this paper is organized as follows: in the next section we expose the core of our proposal (DACME). In section 3 we propose some routing related enhancements to DACME. In section 4 we present some performance results and finally, in section 5, we present our conclusions as well as reference to future work.

2 The distributed admission control mechanism

The admission control mechanism proposed basically requires two DACME agents, one running at the source and one 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, preserved or rejected. Such agents do not require any intervention from the intermediate nodes, except that these forward probe packets as if they were real 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.

In figure 1 we present the functional blocks diagram of the DACME agent. An application that wishes to benefit from DACME must register with the DACME agent by indicating the source and destination 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 registered with DACME. The destination agent, upon receiving probe packets, will update the *Destination statistics* table where it keeps per source information of the 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

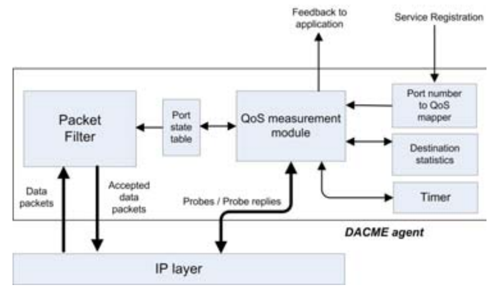

Figure 1. Functional block diagram of the DACME agent

either accept or drop). If only part of the registered connections can be allowed, preference is given to those which have registered first. This module can then notify applications of changes using a feedback call if requested during registration.

The *Packet Filter* module is responsible for looking into the *Port state table* and acting accordingly. This task consists of dropping packets if their source port is in a down state, or setting the IP TOS header field according to the registered QoS otherwise.

Relatively to the probing process, it has been studied in great detail in [3]. In the remaining of this section we will expose succinctly the optimum configuration of the probing process as found in that previous work.

DACME sources are configured to send ten back-to-back packets to the destination per probe. 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 source accepts connections of higher priority causing a performance degradation of its own on-going connections with lower priority; this 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 lost. So, after sending a probe, it sets the timer to go off after 500 ms. If the timer is triggered, or in the case that the probing process is successfully completed, the source will schedule a new probing cycle after 3 seconds $\pm$500ms of jitter to avoid possible negative effects due to probe synchronization.

The DACME agent in the destination, upon receiving the probe, will obtain a measure of available end-to-end bandwidth ($B_{measured}$) by doing:

$$B_{measured} = \frac{8 \cdot P_{size}(bytes)}{AIT},$$

where P_{size} is the size of each probe packet in bytes and AIT is the Average Inter-arrival Time for probe packets. It will then send this estimate value back 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 be able to reach a decision of whether to admit a connection or not. We previously found [3] that

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$B_{measured}$ was a biased estimator for available bandwidth, and so the source agent must correct the bandwidth estimation value before being able to use it. The proposed correction is done using the following expression:

$$B_e = \alpha \cdot \mu_e + \beta \cdot \sigma_e \quad (4)$$

where μ_e is the sample mean, σ_e is the standard deviation of the sample and (α, β) are parameters. The optimum values for these parameters were found using curve fitting techniques.

Taking into account the need to correct the bandwidth deviation, the strategy we propose to perform probabilistic admission control is the one described in algorithm 1.

Algorithm 1 Probabilistic admission control mechanism

After receiving a probe reply ***do*** {
correct the bandwidth estimation
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* }

This algorithm allows reducing the number of probes required to take a decision to a value as low as two probes; it occurs often in those situations where it becomes quickly 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 [3]. 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 in the system.

It should be noticed that the DACME agent or the application itself should always reserve some extra bandwidth to cope with network bandwidth fluctuations, routing data and probes from other sources. For example, we verify that when using AODV and up to 10 DACME sources in a simulation environment, reserving 0.75 Mbit/s of bandwidth is more than enough.

3 Mobility and routing issues

MANETs are caracterized by frequent topology changes. The issue of mobility is usually handled by the routing agent. However, the DACME agent described in the previous section does not interact with routing tasks at all. We consider that DACME, and therefore the application that relies on it, can benefit from obtaining awareness of the state of a path as seen by the routing protocol. Therefore, we improved the implementation of DACME so that the packets that are passed from the IP layer to the QoS measurement module (see figure 1) are not only DACME *probe/probe reply* packets, but also routing packets. The routing protocol we chose for studying was AODV [4]. AODV is a reactive routing protocol that only performs routing tasks when there is actual traffic requiring it. Basically, when a route must be found a RREQ packet is broadcasted throughout the MANET until the destination is reached. The destination will then send a RREP packet back to the source and communication can be started. When a broken link is detected, the node detecting the failure sends a RERR packet to the source that must start a route discovery cycle to find a new valid path.

Relatively to the integration with DACME, we consider that the application's packet flow should not be interrupted when the source is notified that a route is not valid since data packets will be put on queue; also, the route discovery cycle is usually not too long in terms of flow disruption, especially when using IEEE 802.11e. Therefore, we consider that the DACME agent should only act when a new path has already been established so as to assess if the new path can sustain the desired QoS.

There are two situations where the DACME agent will act based on routing information received. In the first situation the DACME agent is idle because the next probe set is scheduled for later. Upon detecting that a RREP packet was received from a DACME destination, the DACME agent will immediately start a new probing cycle. The purpose is to assess the available bandwidth in the new path that has been found. That way, the DACME agent avoids sending data through routes that are possibly congested, improving the overall MANET performance. In the second situation the DACME agent has sent a probe to the destination and is waiting for the reply when a RREP from that destination is received. If no probe reply is received and the timer is triggered, the DACME agent will not consider the path to be down; instead, it sends a new probe to the destination to find out if the path has become available during that short period of time.

We find that this strategy provides enough information from the routing layer, allowing to achieve substantial improvements. The integration of DACME with AODV proposed in this section will be referred to as DACME-AODV from now on.

4 DACME performance in MANETs

In this section we will analyze the performance of DACME using a simulated MANET environment. Such analysis requires the implementation of DACME for the simulation platform of our choice, the ns-2 discrete event

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simulator [9]. In that platform we have changed the structure of mobile nodes so that the DACME agent is able to interrupt the flow of data packets, and perform admission control tasks as desired. We used the IEEE 802.11e module by Wietholter and Hoene [13] and we altered the physical level parameters to upgrade it to IEEE 802.11g. In the following sections we will study the behavior of DACME in a static environment, and then we will proceed by presenting improvements and doing performance analysis in a fully mobile MANET environment.

4.1 Behavior with several sources and no mobility

MANETs are required to adapt not only to congestion changes, but also to node mobility. In this section, however, we will consider that MANET nodes are not moving so that the behavior of DACME can be easily evaluated and understood.

To perform our evaluation we setup a 1900x400 square meters scenario with 50 nodes. All nodes are equipped with an IEEE 802.11g/e interface and the radio range is set to 250 meters. The position of nodes is random, and the average number of hops between the nodes is 4. We use static routing at this stage.

DACME agents handle five CBR traffic sources sending data at a rate of 1 Mbit/s. All packets are set to the Video Access Category. Concerning background traffic, it consists of four sources, each sending negative-exponentially distributed traffic at a rate of 50 packets per second in all four Access Categories defined in IEEE 802.11e. These are *Voice*, *Video*, *Best-effort* and *Background*. The packet size for both CBR and background sources is 512 bytes.

Concerning CBR sources, the first source starts at the beginning of the simulation, and a new source is started every 15 seconds, until all five sources are active. Afterwards, they are turned off in the same order they were turned on.

In figure 2 we show the throughput for each source (maximum is 1 Mbit/s), and the arrows indicate the periods of activity for each source.

We can see that when DACME is not used, sources 1, 4 and 5 suffer from throughput degradation. Such degradation would result in a quality drop if we were in the presence of, for example, video traffic. What we aim is to achieve excellent quality for the streams that are allowed to flow through the MANET; when that is not possible, the streams must not be allowed to access the network. We see that with DACME our purpose is successfully achieved. Now, source 4 is never allowed to transmit since the DACME agent verifies that there is not enough bandwidth at any time throughout its period of activity. Relatively to source 5, we verify that is is allowed to transmit as soon as source 2 stops transmitting, which indicates that the algorithm proposed for DACME is able to react relatively quick to network traffic changes.

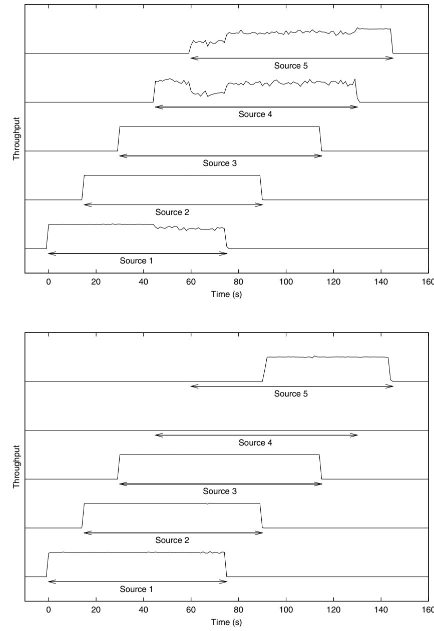

Figure 2. Throughput values for different sources with DACME (bottom) and without DACME (top)

In terms of end-to-end delay, figure 3 shows the improvements obtained with DACME for sources 1 and 5, which are the most representative.

We can see that when DACME is not used the end-to-end delay can reach very high values (close to 500 ms). Such high values are not desirable, and are related to high congestion. We observe that when using DACME the end-to-end delay values are always kept low (usually less that 10ms), though we can observe a periodic variability pattern. Such occurrence is directly related to the probing process, periodically repeated every 3 seconds (plus jitter), and therefore cannot be avoided. We should point out that such variability depends on the path congestion and on the data rate of the application.

We now proceed to analyze DACME performance in terms of several parameters. The results are presented in table 1. We observe that DACME traffic represents about 32 to 64 kbit/s of overhead. In this scenario only a few probe packets were lost, and therefore probe replies were sent and reached the source successfully every time. We also observe that the average cycle time is intimately related to the number of hops as expected, though congestion also plays an important role (see differences between source 2 and 3).

We also consider important to assess how many probes had to be sent each time to reach a conclusion relative to weather to accept a connection or not. We can see that sources 2, 3 and 4 were usually able to reach a decision

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Table 1. DACME statistics

	Source 1	Source 2	Source 3	Source 4	Source 5
Probe packets generated	1140	770	720	680	1120
Probe packets lost (%)	0.614	0.000	0.000	3.382	0.738
Avg. probe/reply time (ms)	33.804	4.813	3.174	57.891	40.769
Avg. number of probes req.	4.54	2.96	2.5	2.54	4.62
Avg. cycle time (ms)	157.414	15.098	8.297	147.015	194.055
Num. hops to destination	5	1	1	7	5

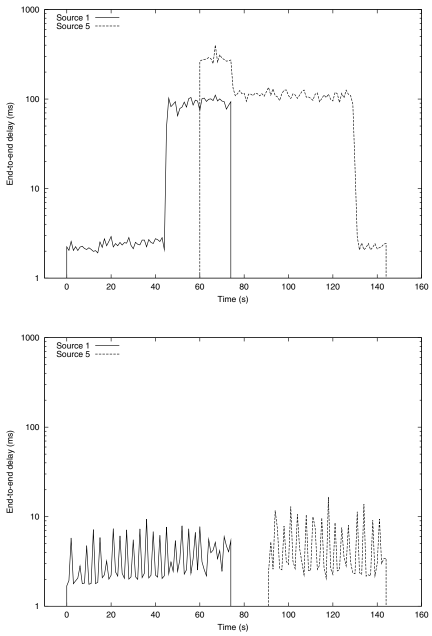

Figure 3. End-to-end delay values for sources 1 and 5 with DACME (bottom) and without DACME (top)

with only 2 or 3 probes. On the contrary, sources 1 and 5 usually found that available bandwidth was very close to the desired value, and so typically required the maximum number of consecutive probes allowed (5).

If we take into account this result, and if we also notice that in figure 2 activity periods are kept very stable, we can conclude that the strategy followed in algorithm 1 (maintain the previous path state when no decision can be taken) is adequate and promotes stability from both user and network points of view.

4.2 Performance in a typical MANET environment

In this section we will assess the effectiveness of both DACME and DACME-AODV in a typical MANET environment. With that purpose we use ns-2 to simulate an environment where 50 nodes move at a constant speed of 5 m/s in a 1900x400 square meters scenario according to the random waypoint mobility model. As previously, radio interfaces are IEEE 802.11g/e enabled and the radio range is 250 meters, leading to an average of 4 hops between nodes.

Relatively to traffic, we have four background sources that are generating negative-exponentially distributed traffic in the *Video*, *Best Effort* and *Background* MAC Access Categories. Contrarily to section 4.1, we do not set the same data rate to the different MAC Access Categories. Instead, we set 50% of the traffic to the *Video AC*, and the remaining 50% is evenly divided among the *Best Effort* and *Background ACs*. Relatively to the *Voice AC*, the only Voice traffic belongs to DACME sources. This difference is due to the need to perform routing tasks; since routing traffic is also set to the *Voice AC* (highest), we limit the amount of Voice traffic to avoid routing misbehavior.

Concerning the data sources under study (regulated by 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. 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. All the results presented are average values over several simulation runs.

Figure 4 shows the improvements in terms of video goodput and voice packet losses using DACME and DACME-AODV compared to a solution where DACME is not used (turned off). We can observe that when DACME is not used the average goodput of the video sources drops steadily with increasing congestion. By using DACME the average goodput is maintained close to maximum because sources are only allowed to transmit if the DACME agent verifies that the available bandwidth is enough. Obviously, as the congestion level increases the amount of DACME-regulated traffic accepted into the network decreases. From figure 4 we can also observe that DACME offers great improvements in terms of voice packet losses; as expected, DACME-AODV offers a better performance than the de-

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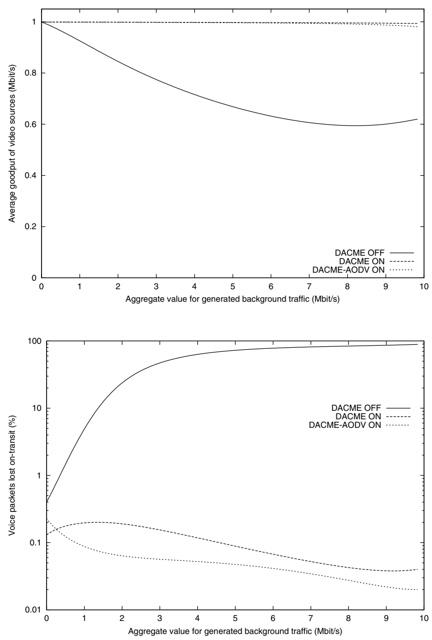

Figure 4. Improvements in terms of video goodput (top) and voice packet losses (bottom) by using DACME and DACME-AODV

fault DACME implementation.

We now proceed to evaluate the performance achieved in terms of end-to-end delay. The results are shown in figure 5. We see that when using DACME the end-to-end delay for both Voice and Video sources is greatly improved. Comparing DACME with DACME-AODV we see that the differences in terms of average values are only slight. In the next sections we will present further details on this issue.

By controlling the amount of traffic admitted into the MANET, DACME also offers interesting improvements in terms of routing overhead and routing effectiveness.

In figure 6 we can see these improvements clearly. These results are in accordance with the analysis we performed in [2] relatively to the interaction between traffic and reactive routing protocols.

We will now proceed to study in more depth the performance under low, moderate and high congestion levels. These congestion levels map, in terms of aggregated value for generated background traffic, to the values: 650 kbit/s, 2.3 Mbit/s, and 6.5 Mbit/s respectively.

4.2.1 Low congestion environment

In this environment we observe that there are relatively few packets blocked by to the DACME agent, and very few packet drops in the network. So, it is only meaningful to observe the performance in terms of end-to-end delay. In figure 7 we show the end-to-end delay results for both video and voice sources. We can observe that both DACME versions offer improvements relatively to a non-DACME scenario. We also observe that for video traffic DACME performs better that DACME-AODV; this occurs since DACME packets use the same MAC Access Category as video packets, which increases the delay. In terms of Voice packets, DACME-AODV offers much better results.

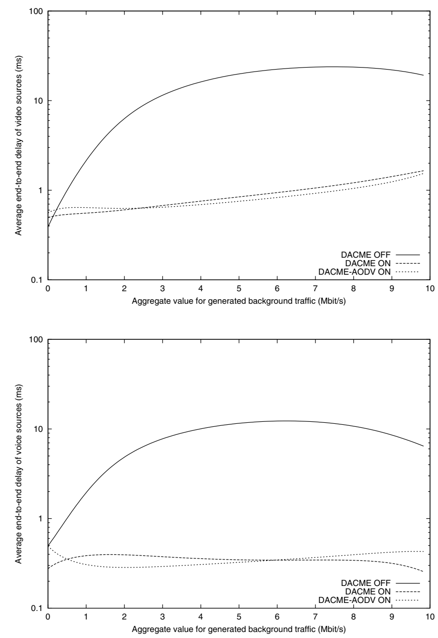

Figure 5. Average end-to-end delay values for video (top) and voice (bottom) sources.

4.2.2 Moderate congestion environment

We will now analyze what occurs in the MANET with a moderate degree of congestion. Simulation results show that the throughput of video sources is maintained much steadier when using DACME. We also observe that there are some ocasional traffic interruptions, and that the rate of those interruptions is closely related to the rate of topology changes caused by mobility.

If we observe the number of packets dropped in the network (see table 2) we can also see that using DACME offers much better results, avoiding unnecessary waste of resources. Notice that DACME-AODV performs slightly better that DACME, as expected.

In terms of end-to-end delay (see figure 8), we again see a clear performance improvement by using DACME, with DACME-AODV offering similar performance in terms of Video traffic, and a much better performance for Voice traffic.

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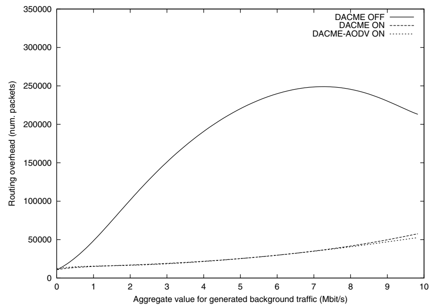

Figure 6. Routing overhead

Table 2. Number of video packets dropped in the network under moderate congestion

	DACME off	DACME on	DACME--AODV on
Video src. 1	4295	19	40
Video src. 2	11176	66	48
Video src. 3	14079	118	41
Video src. 4	4945	10	35
Total loss	34495	213	164
Loss (%)	29,43	0,92	0,78

4.2.3 High congestion environment

When the MANET environment is highly congested the impact of admission control techniques becomes even more evident. In terms of the throughput of video sources, both DACME versions achieve very steady throughput levels. DACME and DACME-AODV also continue to achieve very low packet loss rates for both Video and Voice traffic.

In terms of end-to-end delay figure 9 shows that, when congestion is high, the benefits of introducing routing awareness are reduced. In fact, DACME-AODV offers worse results than plain DACME for video traffic (though for only less than 1% of the traffic), and the improvements in terms of Voice traffic are minimal.

Such results are expected since routing awareness provokes more frequent measurements; this extra traffic penalizes performance slightly under high congestion.

5 Conclusions and future work

In this paper we presented DACME, a distributed admission control architecture to support multimedia services in MANETs. Our proposal can be easily deployed since it imposes very few requirements on MANET nodes. In fact, MANET stations only need to have IEEE 802.11e capable interfaces and to handle packets according to the TOS field in their IP header.

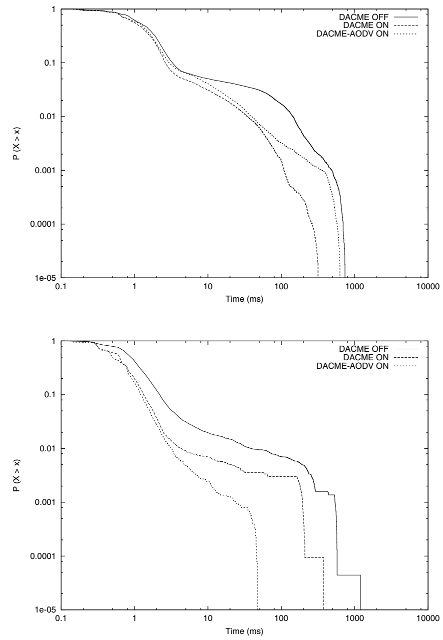

Figure 7. End-to-end delay distribution for the video (top) and voice (bottom) sources under low congestion

Simulation results show that DACME offers a reliable admission control technique at different levels of congestion. Overall, it improves performance and avoids wasting MANET resources. We observe that enhancing DACME with routing awareness can also improve the performance achieved.

As future work we plan to enhance DACME with end-to-end delay and delay jitter probing capabilities, as well as integrating DACME with a multipath-enabled version of DSR.

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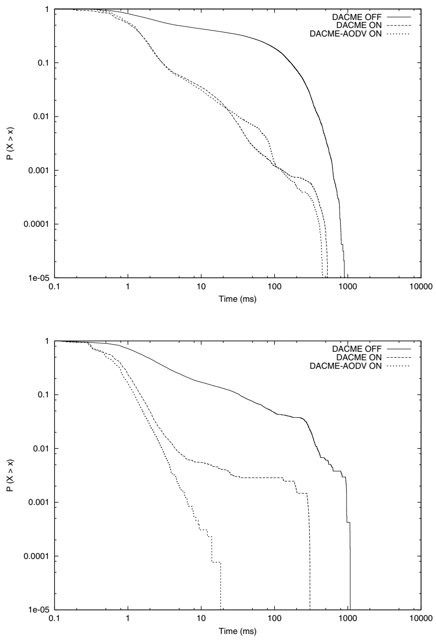

Figure 8. End-to-end delay distribution for the video (top) and voice (bottom) sources under moderate congestion

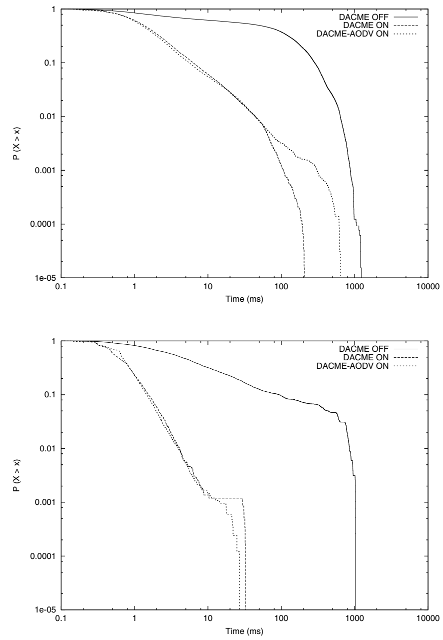

Figure 9. End-to-end delay distribution for the video (top) and voice (bottom) sources under high congestion

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