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A distributed admission control system for MANET environments supporting multipath routing protocols ☆

Carlos T. Calafate [a,*], José Oliver [a], Juan-Carlos Cano [a], Pietro Manzoni [a], Manuel P. Malumbres [b]

[a] *Department of Computer Engineering, Technical University of Valencia (UPV), Camino de Vera, S/N, 46002 Valencia, Spain*
[b] *Department of Physics and Computer Engineering, Miguel Hernandez University (UMH), Av. Libertad S/N, 03202 Elche, Spain*

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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 an admission control strategy that can operate both over single and multipath routing protocols. The results achieved through simulation 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 such as real time video and voice applications.

Keywords: MANET; QoS support; Distributed admission control; Multipath routing; IEEE 802.11e

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 in the unlicensed 5 GHz band. The IEEE 802.11e [2] 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. Examples of QoS traffic include VoIP, videoconference and that generated by any other real-time application.

Supporting real-time video and voice traffic in MANETs is an upcoming need that results from the fusion of two technological areas that have been receiving much interest in the past few years. On the one hand, the proliferation of devices with embedded audio/video capturing and processing capabilities has made videoconference the new human communication paradigm. On the other hand, recent improvements in network technologies aim at supporting

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* Corresponding author. Tel.: +34 963877007x75727; fax: +34 963877579.
E-mail addresses: calafate@disca.upv.es (C.T. Calafate), joliver@disca.upv.es (J. Oliver), jucano@disca.upv.es (J.-C. Cano), pmanzoni@disca.upv.es (P. Manzoni), mels@umh.es (M.P. Malumbres).

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mobile wireless communications through self-configuring and fully flexible networks. Therefore, one of the greatest technological challenges to be met, according to the current state-of-the-art, is providing real-time peer-to-peer video-conference systems in MANETs. To achieve this goal QoS support stands as a *sine qua non* condition.

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 QoS-related problems.

The rest of this paper is organized as follows: in the next section we refer to related works in the field. In Section 3 we make a brief reference to the multi-path routing protocol that will be used to validate DACME in environments where traffic is split among multiple paths. In Section 4 we expose the core of our proposal (DACME) and, in Section 5, we present some performance results. Finally, in Section 6, some conclusions are drawn, along with references to future work.

2. Related work

The issue of QoS support in MANETs has received much attention lately due to its significance in terms of enabling the delivery of real-time services over these networks. Due to the complexity of supporting QoS in MANETs, most of the proposals available in this field focus solely on a single protocol layer, usually the MAC or the routing layer.

In terms of MAC layer protocols for ad hoc networks, the IEEE 802.11 Work Group E [2] has recently completed a new MAC standard, also denoted as *IEEE 802.11e*, to enhance Wi-Fi networks with QoS support; in the literature we can find works on the performance of this technology in multi-hop MANET environments [3]. In [4] Romdhani et al. propose enhancements to the IEEE 802.11e technology to offer relative priorities by adjusting the size of the Contention Window (CW) of each traffic class, taking into account both applications requirements and network conditions. Sobrinho and Krishnaku-mar propose Blackburst [5], a novel distributed channel access scheme that is more efficient than the IEEE 802.11e technology. Other works such as [6–8] also propose alternate QoS MAC schemes designed specifically for ad hoc network environments.

Concerning proposals of QoS-enhanced routing protocols for MANETs, Lin and Liu [9] propose a QoS routing protocol that includes end-to-end bandwidth calculation along with bandwidth allocation schemes. Shigang and Nahrstedt [10] define a distributed QoS routing scheme that selects a network path with sufficient resources to satisfy a certain delay (or bandwidth) requirement. In [11], Xue and Ganz propose a resource reservation-based routing and signaling algorithm (AQOR) that provides end-to-end QoS support in terms of bandwidth and delay. Badis and Al Agha propose the QOLSR protocol [12], which is an enhancement of OLSR [13] to support multiple-metric QoS routing. Also, Chen and Heinzelman [14] propose a QoS-aware routing protocol that incorporates admission control and feedback schemes to meet the QoS requirements of real-time applications by offering an estimate of available bandwidth.

In terms of proposals that integrate several protocol layers so as to achieve a complete QoS architecture, in the literature we can find only a few. The most well-known works offering a complete QoS framework are INSIGNIA [15], SWAN [16] and FQMM [17].

INSIGNIA is an approach to Integrated Services support in MANETs based on a flexible 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. SWAN is an approach to Differentiated Services support in MANETs that relies on plain IEEE 802.11, and where best effort traffic is regulated through a rate-control mechanism; traffic acceptance is dependent on local bandwidth estimates through admission control probes. FQMM is the first QoS model targeting solely MANETs. It uses a hybrid per-flow and per-class provisioning scheme where highest priority traffic is given per-flow QoS provisioning, while other category classes are given per-class QoS provisioning.

To the best of our knowledge no complete QoS framework for MANETs has been proposed 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.

3. MDSR: a multipath extension of DSR

In a previous work [18] we proposed an extension to the Dynamic Source Routing protocol (DSR) [19] 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 [18] for more details).

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

4. The distributed admission control mechanism

4.1. Design considerations

MANETs do not follow the Internet's Client/Service provider paradigm IntServ and DiffServ were created for. The development of a QoS framework for MANETs requires a much more flexible philosophy of cooperation and resource sharing among users. In fact, the concept of MANET itself somehow implies the existence of users, except in situations where special nodes have been deployed at a particular location to form some sort of infrastructure, offering more reliability to a particular MANET. The ''ad hoc'' concept in that situation, though, drops the notion of spontaneity.

In MANETs we can devise two main policies for resource management and user control. The first one follows the centralized control paradigm, where one person or entity has practically all the control of the devices themselves, both in terms of their components (including hardware and software), as well as control on how users will operate the devices. An example of this can be a military unit or a firemen rescue group, where both devices and users follow strict policies and rules. The centralized control paradigm allows optimal operation and much flexibility at all levels in order to achieve the best QoS support possible. However, it can only be deployed in very limited situations.

The second one drops the centralized control paradigm, embracing a much softer one of cooperation among equals. This cooperation may be based on willingness to achieve mutual benefit, or enforced through punishment of selfish nodes. Anyway, there is always a notion of strong dependency among users and complex interactions in the network, which can be remarkably well described using game theory when nodes behave selfishly. Urpi et al. [20] develop a formal explanation of the characteristics of ad-hoc networks, using the Nash equilibrium to analyze strategies that stimulate cooperation among nodes. We consider that, in those MANET environments where this second paradigm applies, reserving resources of others can be difficult or impossible to accomplish.

In real-world scenarios we usually do not have full control of all the stations in the MANET, as in the first paradigm. So, we can expect that stations will, at most, use standard routing protocols on top of standard MAC/PHY radio interfaces. However, even when we have full control of all devices, making strict QoS reservations is still a very complex issue. Wang et al. [21] proved that, in a wired environment such as the Internet, if the QoS requirements contain two additive metrics (e.g. cost, delay, delay jitter) or more, QoS routing is an NP-complete problem. In multi-hop, mobile wireless environments, performing resource reservation alone is a complicated task; in [22] Georgiadis et al. 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. This means that the per-node local measurements do not offer enough data for end-to-end bandwidth reservation, which makes difficult the implementation of bandwidth reservation schemes for MANETs (e.g. those proposed in the frameworks of INSIGNIA and SWAN).

Taking into account all these issues, we take a more pragmatic approach by proposing a QoS architecture that is simultaneously effective in MANET environments, quickly deployable using currently available devices and technologies, and lightweight in terms of resource consumption on mobile terminals. This means that we avoid any technique where all stations are required to keep track of the MAC's transmission delay or the Signal-to-Noise Ratio (SNR) for each packet being processed, to apply rate control and bandwidth estimation algorithms, etc.

Besides taking the aforementioned issues into consideration, we want to be able to support any sort of multipath routing strategy, such as the one presented in Section 3, while maintaining the admission control and the routing layers decoupled.

We consider that 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 end-to-end measurements have to handle lost and out-of-order packets. 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(s) start dropping QoS-demanding packets.

We now proceed to detail DACME, the proposed admission control system whose design took into consideration all these issues referred up to now.

4.2. Implementation details

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 [2].

In Fig. 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 a callback function if 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 [23], 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 priority is also known as the *stolen bandwidth problem* [24].

The DACME agent in the destination, upon receiving the probe, will obtain a measure of available end-to-end bandwidth; this value is obtained through the following expression:

$$B_{\text{measured}} = \frac{8.P_{\text{size}}}{\text{AIT}}, \tag{1}$$

where P_{size} is the size of each probe packet in bytes, and AIT is the Average Inter-arrival Time for probe packets. The Average Inter-arrival Time (AIT) is defined as:

$$\text{AIT} = \frac{\Delta t_{\text{rec}}}{N-1}, \tag{2}$$

where Δt_{rec} is the time interval between the first and the last packet arriving, and N is the number of packets received (not the number of packets sent).

Once calculated, B_{measured} is returned to the source on a probe reply packet. The DACME source agent, when receiving each probe reply packet, will store the B_{measured} value sent by the destination agent. The different bandwidth

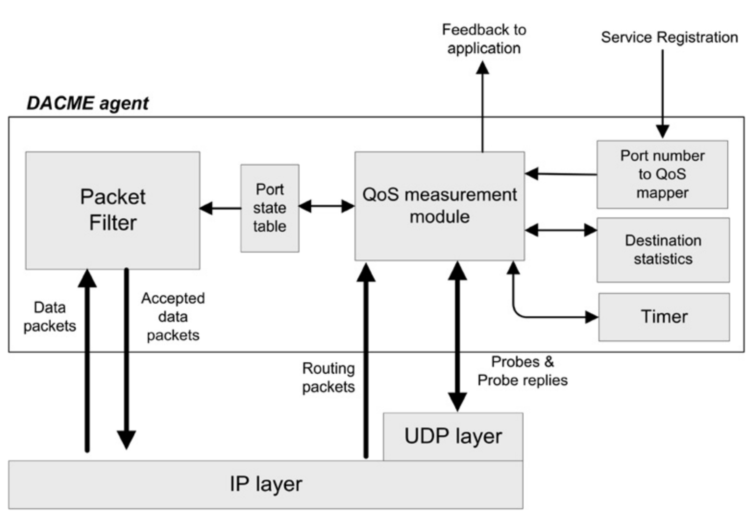

Fig. 1. Functional block diagram of the DACME agent.

estimations collected are used to reach a decision on whether to admit a connection or not.

Analysis of the bandwidth probing results show that the sample mean is a biased estimator for the available bandwidth. To clearly depict this phenomena we present the discrete probability distribution for the probing process at three distinct congestion levels on a static scenario where source and destination are four hops away from each other. We obtain the distributions by splitting the range of results from each probing process into fifteen intervals of equal length. Results are shown in Fig. 2. The arrow/letter pairs refer to available bandwidth measurements made with real traffic, and are used as reference for comparison.

Algorithm 1. Probabilistic admission control mechanism

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*}

As it can be seen, the three probability distributions are not centered around the reference values (H, A, and L), which explains why their mean is superior to the real traffic measurements. Also, we notice that average levels of congestion tend to favor lower kurtosis values (see [23] for further details).

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.

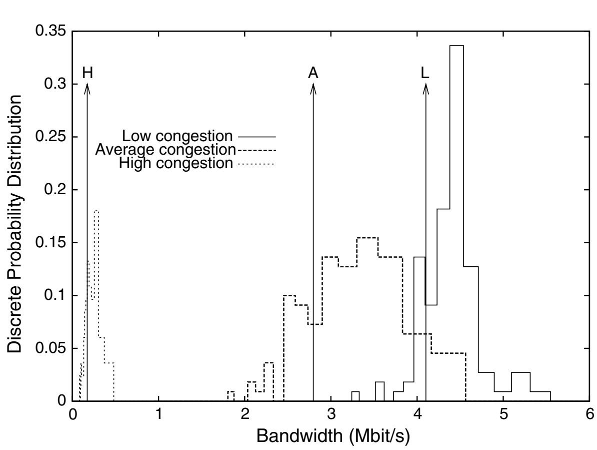

Fig. 2. Discrete probability distribution for the probing process under low, average and high levels of congestion.

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. 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 [23]. 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, as well as to offer room for best effort traffic. See [25] for more information on this issue.

4.3. Coping with mobility and loss: timers

When designing an algorithm for a lossy mobile network environment we should always take care of handling losses in a clear and straightforward manner. In DACME this loss awareness is gained by recurring to timers, being a central element of both source and destination DACME agents.

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. 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 s ±500 ms of jitter to avoid possible negative effects due to probe synchronization. This value was chosen from the ''Hello''-based version of AODV, where the authors determine that a reaction time of 3 s 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 destination agent must accommodate to the possibility that not all the packets of a probe arrive. So, when the destination receives the first packet, it updates the current sequence number. When the second or the following packets are received it continuously updates an internal timer, setting it go off after:

$$T = \frac{T_{\text{last}} - T_{\text{first}}}{N_{\text{recv}} - 1} \cdot (N_{\text{rem}} + \epsilon) + \tau, \qquad (3)$$

where T_{last} and T_{first} are the times of arrival of the last and first packet received, N_{recv} is the number of packets currently received, N_{rem} is the number of packets that remain (not received yet), and ε is a fixed number of additional packets used to model a certain degree of tolerance; in our experiments we set this parameter to three packets. While in the first part of the expression we try to accommodate dynamically to the observed network performance, there are situations where we cannot predict the timeout value correctly; an example is a MANET where the routing protocol splits traffic through multiple paths. So, to take into account such situations, we also add τ, a small constant time value; in our experiments it is set to 50 ms since our analysis of MDSR showed that the typical delay differences between different routes is normally less than this value.

Relatively to the maximum packet loss rate allowed, it may occur that, when traffic is split through multiple paths, one of the paths is down. In that situation only a subset of the packets in a probe would arrive. To avoid accepting such measurements as valid we impose that the number of probe packets received should be of more than half in case the routing protocol splits traffic through two different paths (using two alternative paths is the most common case, and also applies to the MDSR routing protocol). If the timer goes up and the destination did not receive enough probe packets, it notifies such event to the source.

5. 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 [26] discrete event simulator. All simulations are carried out in a typical MANET environment sized 1900×400 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 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 m, 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 [27] for more details on this problem).

Concerning the data sources under study (regulated by DACME), these consist of four video streams and three voice streams. The video sources are simulated using 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 s a new data source becomes active, alternating between voice and video sources. Each source is active for 2 min, and all results presented are average values over 10 simulation runs.

The results found in the next two sections show that using DACME can clearly avoid the waste of resources by interrupting communication when the minimum QoS requirements are not met. Besides, DACME is able to sustain performance independently of node speed up to 13 m/s. Afterwards traffic admission rates are dropped, but performance is sustained.

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.

5.1. Performance under varying degrees of congestion

In this section we study the performance of DACME when varying the amount of background traffic generated. The purpose is to assess its effectiveness for different levels of resource availability. For this set of experiments nodes are moving at a constant speed of 5 m/s.

Fig. 3 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.

From Fig. 3 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.

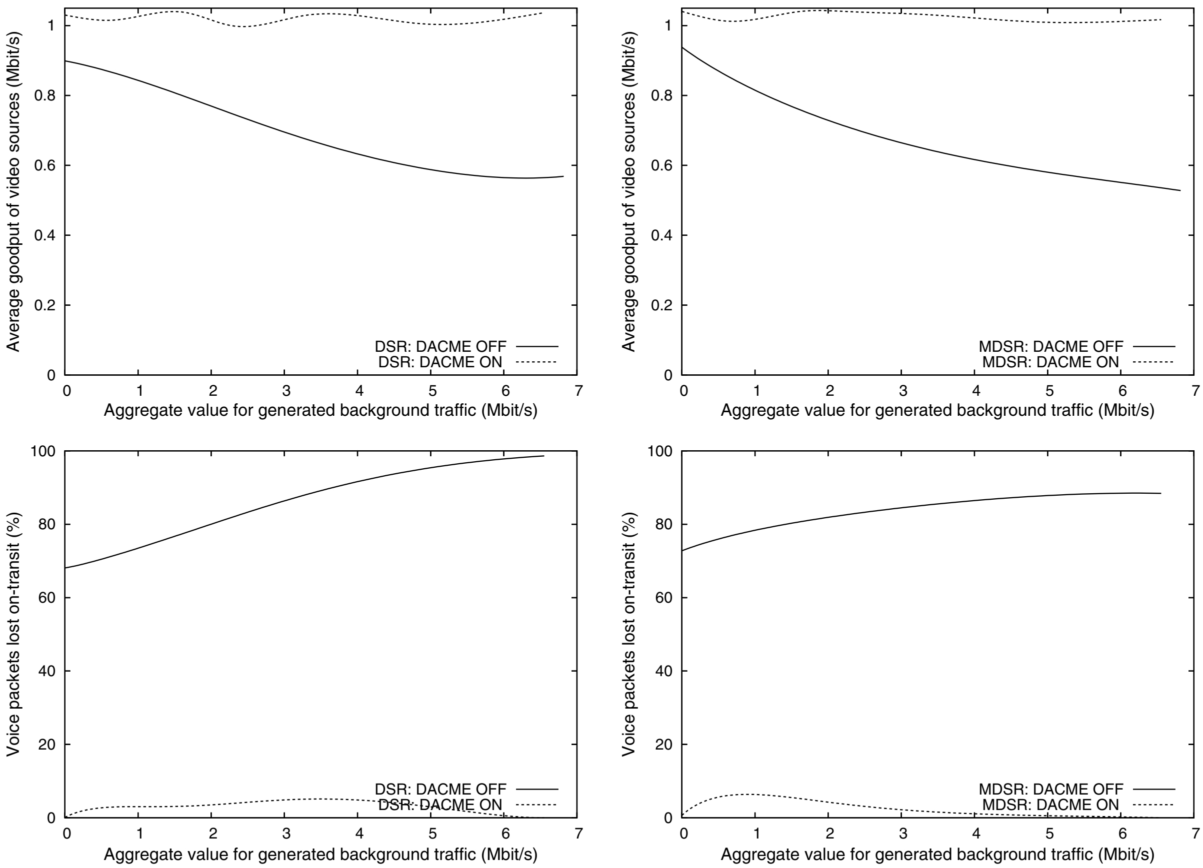

Fig. 3. Improvements on video goodput (top) and voice packet drops (bottom) by using DACME with DSR (left) and MDSR (right).

We now proceed to evaluate the performance achieved in terms of end-to-end delay. The results are shown in Fig. 4. 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 Fig. 5 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 [27].

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 Fig. 6 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.

We will now proceed to study in more depth the behavior under low, moderate and high congestion levels, which correspond to setting the aggregated background traffic to 0.65, 2.3, and 6.5 Mbit/s, respectively.

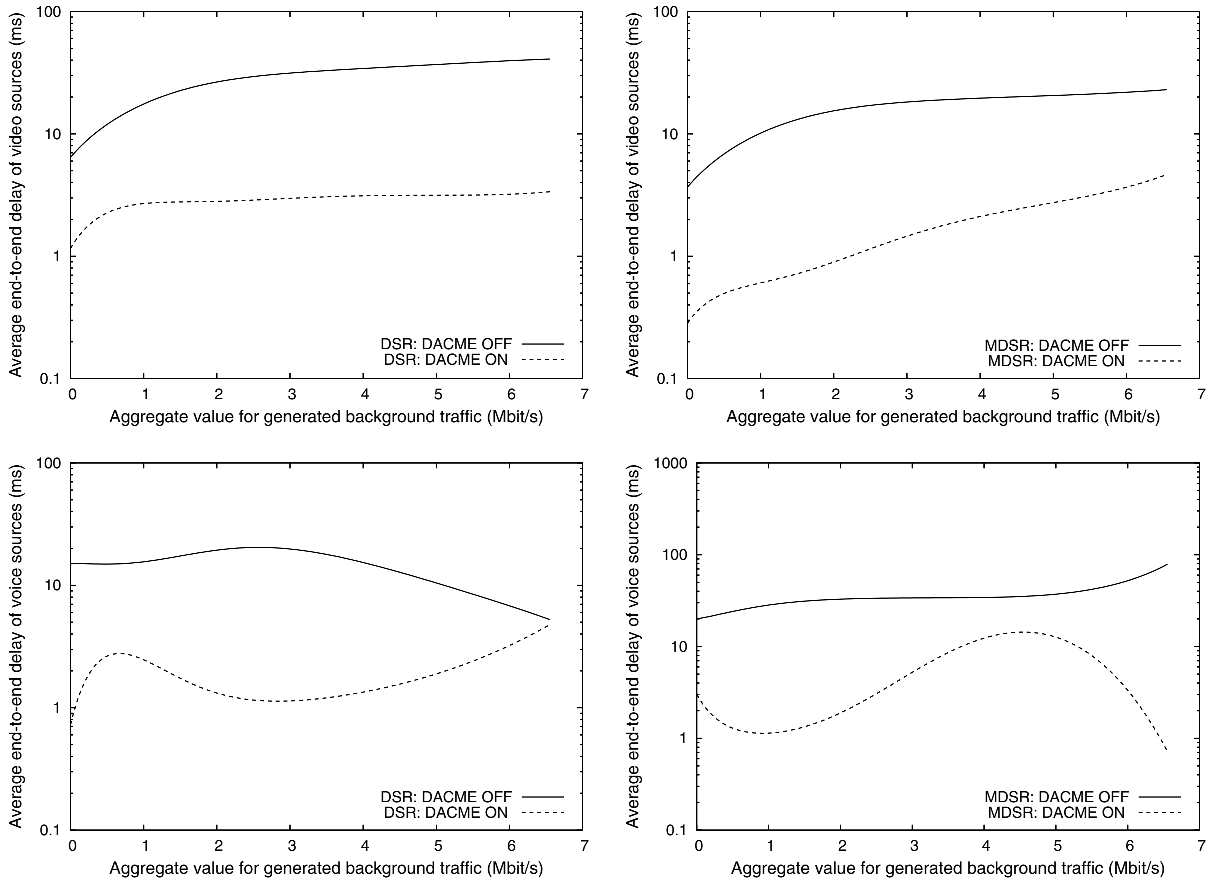

Fig. 4. Average end-to-end delay values for video (top) and voice (bottom) sources for DSR (left) and MDSR (right).

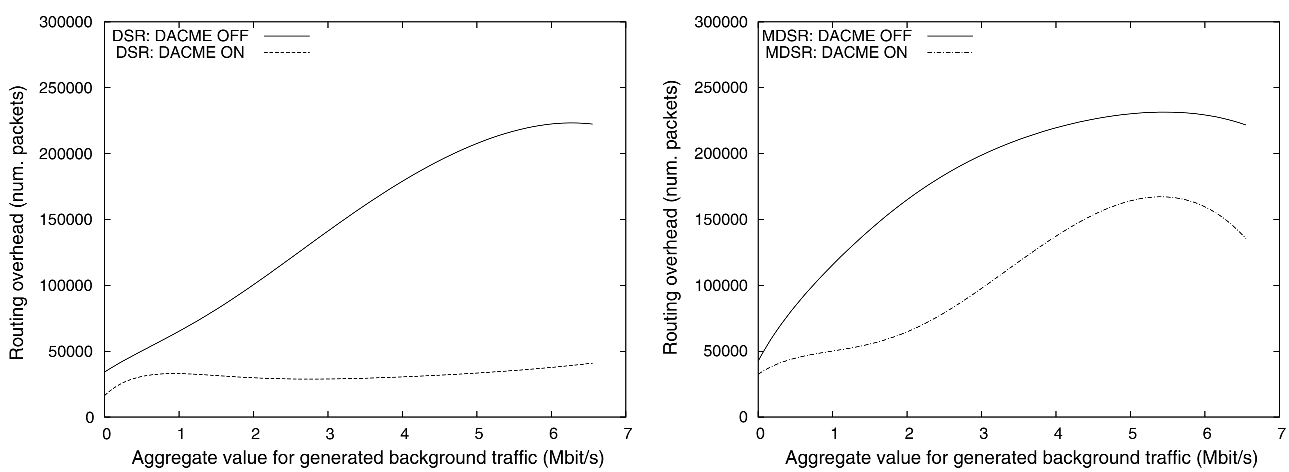

Fig. 5. Routing overhead for DSR (top) and MDSR (bottom).

5.1.1. Low congestion environment

Under low congestion the amount of background traffic is relatively low, which results in a greater interaction between the distinct DACME-regulated sources. In Fig. 7 we show that in this situation DACME already offers benefits, maintaining steadier levels of throughput for all video sources with both DSR and MDSR. It is interesting to notice that when DACME operates in conjunction with DSR it behaves in a conservative manner, blocking connections often; the MDSR plus DACME solution offers better results by increasing the total time of activity.

In terms of end-to-end delay, Fig. 8 shows that DACME offers important improvements for both DSR and MDSR routing protocols, even when the congestion on the MANET is relatively low. We also observe that the best

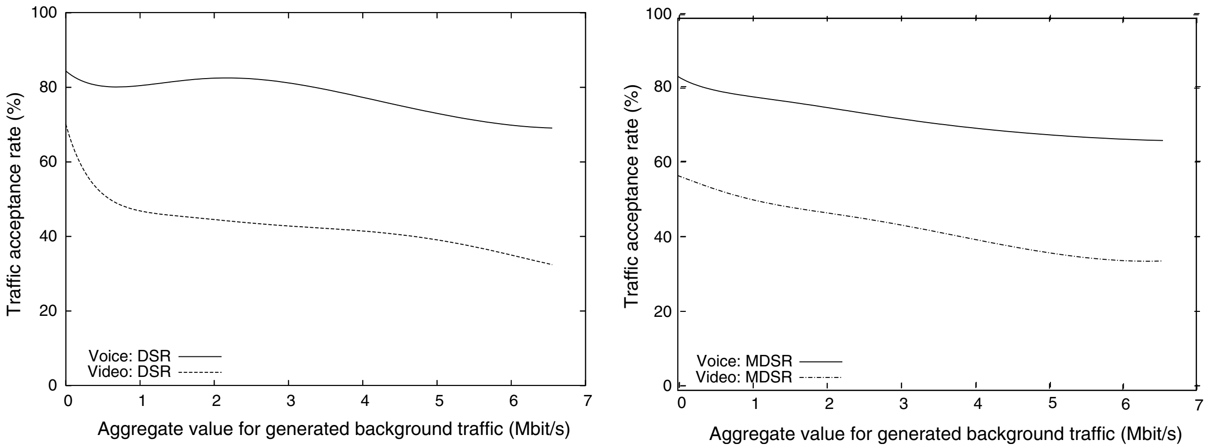

Fig. 6. Percentage of admitted traffic using both DACME versions at different congestion levels for DSR (left) and MDSR (right).

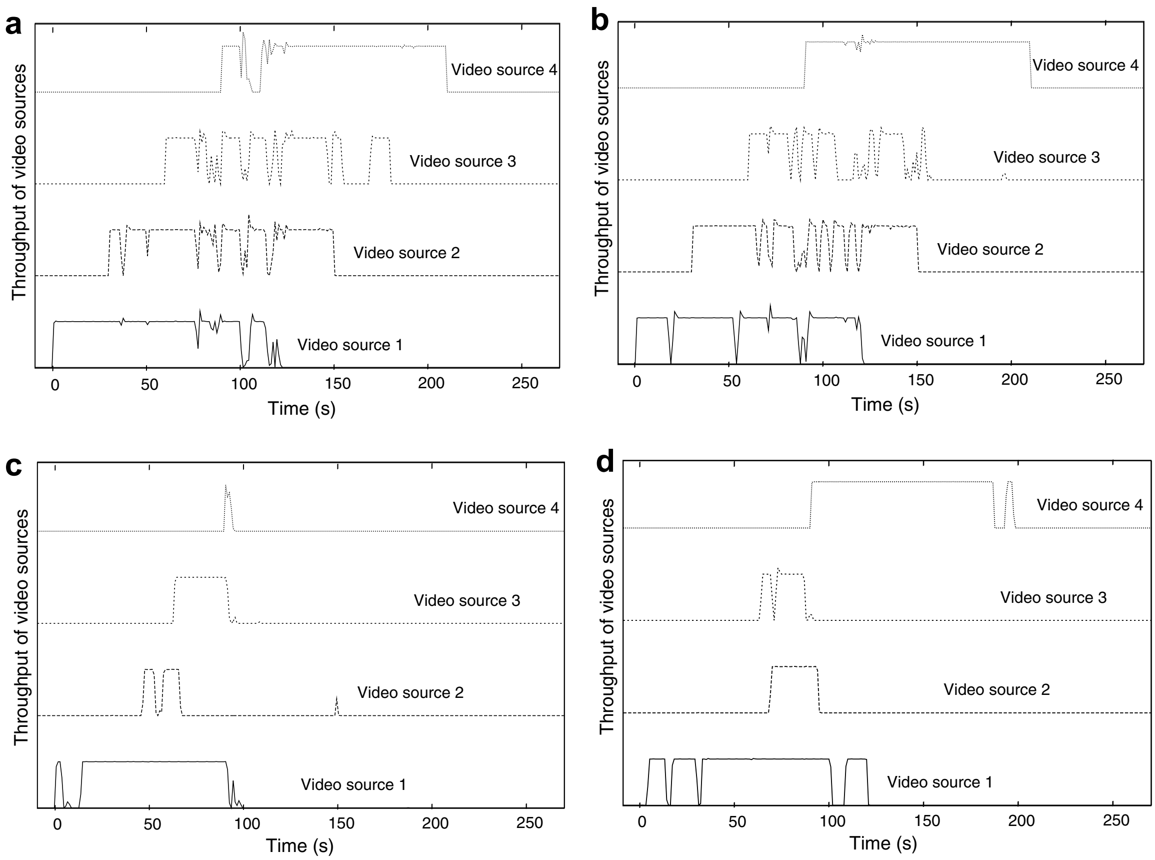

Fig. 7. Throughput variation with time for the video sources using (a) DSR, (b) MDSR, (c) DSR+DACME, and (d) MDSR+DACME under low congestion.

performing solution for the highest share of traffic is DSR with DACME; we consider that this is due to the increased number of hops that part of the traffic has to go through during some periods when relying on MDSR. However, the MDSR plus DACME solution is more effective in reducing the amount of packets that reach the destination with very high delay values, especially for Voice data where none of the packets arrives with a delay above 150 ms.

The results found until now show that DACME is also effective when used in conjuction with a multipath routing protocol. We will now proceed with our evaluation under moderate congestion, and verify if the effectiveness of DACME with MDSR persists.

5.1.2. Moderate congestion environment

In this environment the level of background congestion is enough to cause important losses to both video and voice

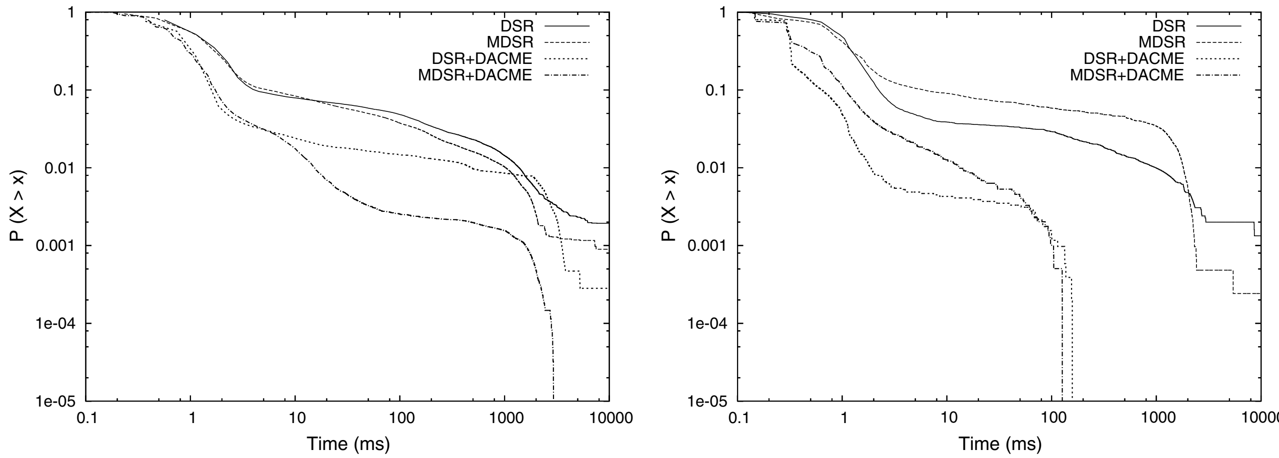

Fig. 8. End-to-end delay variation with time for the video (left) and voice (right) sources under low congestion.

data streams (see Fig. 9). In this situation the use of DACME brings even more benefits than in the previous scenario with low congestion, not only because the video throughput is maintained at much steadier levels, but also because the number of packets lost on-transit is greatly reduced.

In Table 1 we show the number of packets lost in the network due to multiple factors such as routing, full queues or MAC related drops. We observe that MDSR performs much better than DSR, reducing losses by an order of magnitude. Such improvement is essentially related to the traffic splitting algorithm used by MDSR. These loss levels are quite acceptable for a MANET environment and, compared to the non-DACME results, show that by using DACME we also save energy resources on MANET nodes by only forwarding packets when the chances of reaching the destination are high.

If we now study the behavior in terms of end-to-end delay (see Fig. 10), we can again notice DACME's

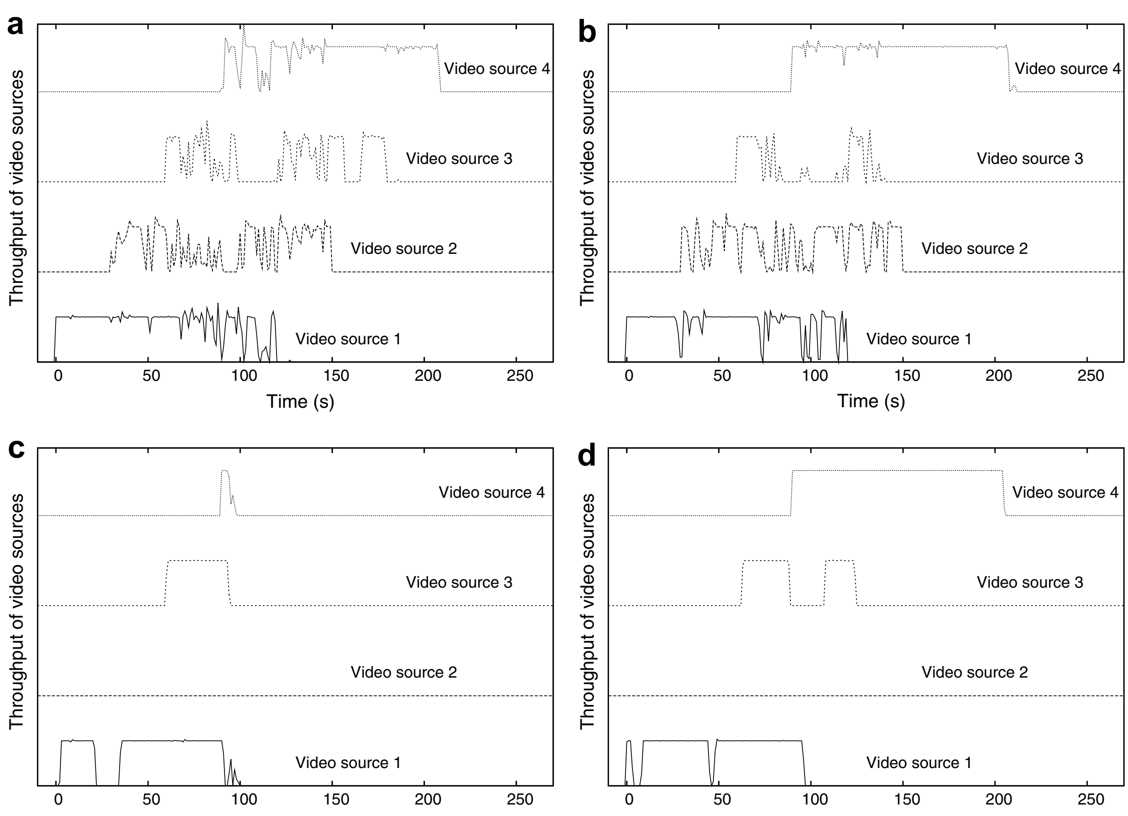

Fig. 9. Throughput variation with time for the video sources using (a) DSR, (b) MDSR, (c) DSR+DACME, and (d) MDSR+DACME under moderate congestion.

Table 1
Number of video packets dropped in the network

	DSR	MDSR	DSR+DACME	MDSR+DACME
Video source 1	3036	3292	488	60
Video source 2	11249	9229	0	1
Video source 3	13745	21821	0	7
Video source 4	3039	614	144	0
Total loss	31069	34956	632	68
Loss (%)	26,5	29,82	2,17	0,11

effectiveness. In terms of video traffic we see that DSR and MDSR combined with DACME offer similar results, though MDSR performs slightly better. Relatively to voice traffic, the performance achieved by using DSR plus DACME slightly surpasses that achieved with MDSR plus DACME, though it is prone to generate more packets with very high delay values.

The results found in this section further sustain the applicability of the DACME admission control algorithm

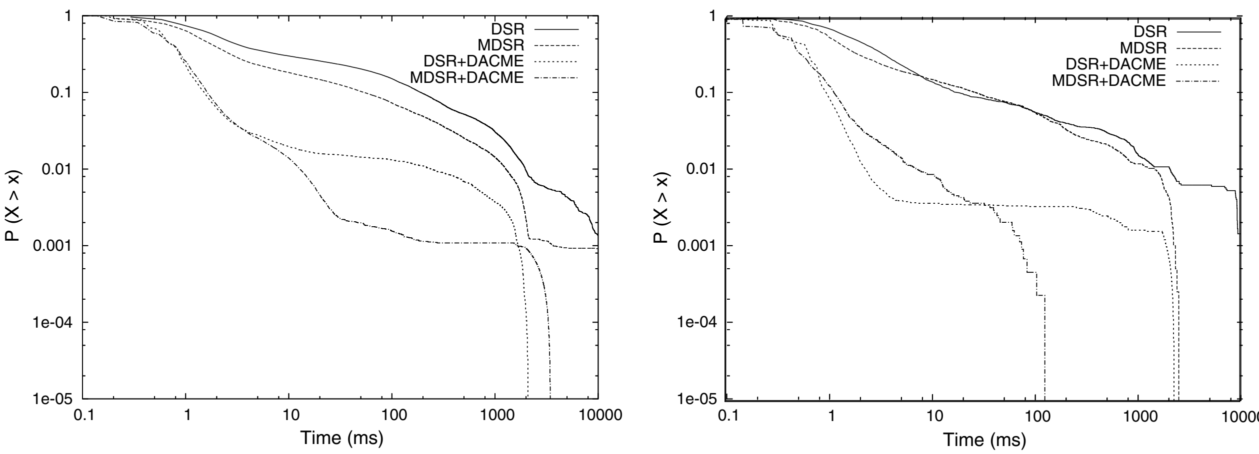

Fig. 10. End-to-end delay variation with time for the video (left) and voice (right) sources under moderate congestion.

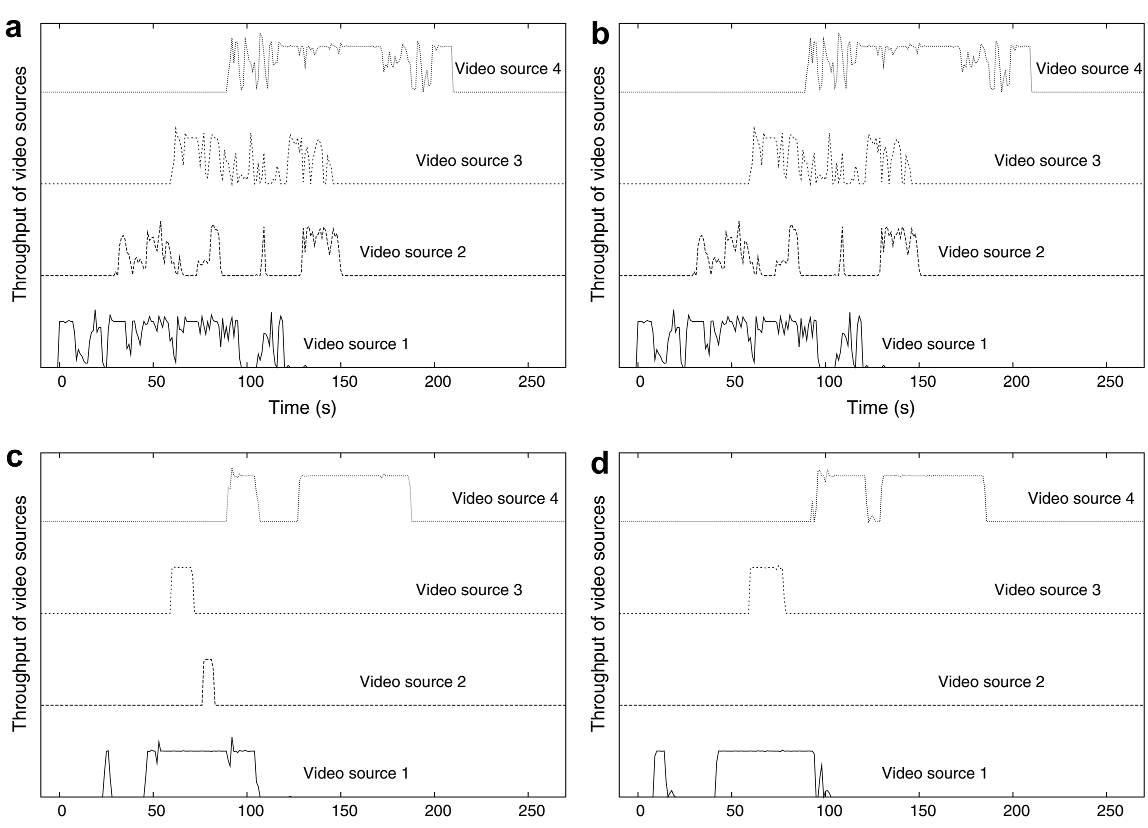

Fig. 11. Throughput variation with time for the video sources using (a) DSR, (b) MDSR, (c) DSR+DACME, and (d) MDSR+DACME under high congestion.

with a multipath routing protocol, showing no signs of misbehavior or poor performance. We now proceed to analyze in detail the performance under high congestion.

5.1.3. High congestion environment

When the MANET environment is highly congested, it is especially important for sources generating high data rates to avoid transmitting. If no type of admission control is performed, though, the network congestion will increase even further and these high data rate sources will consume resources unnecessarily. This is what occurs in the current situation where we observe (see Fig. 11) that the different video sources can barely succeed in transmitting data to the destination when DACME is not used.

When DACME is used we see that the situation changes: most of the time the video sources are not allowed to

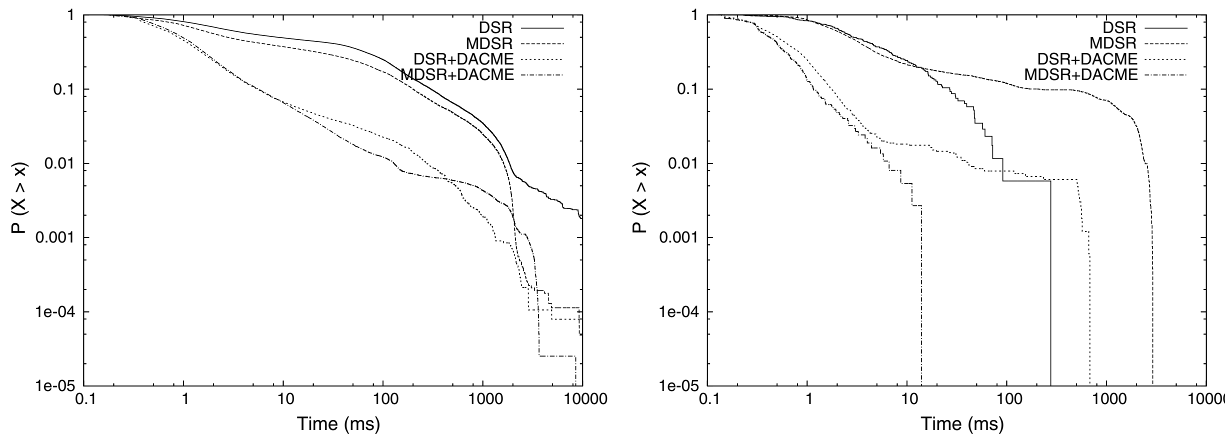

Fig. 12. End-to-end delay variation with time for the video (left) and voice (right) sources under high congestion.

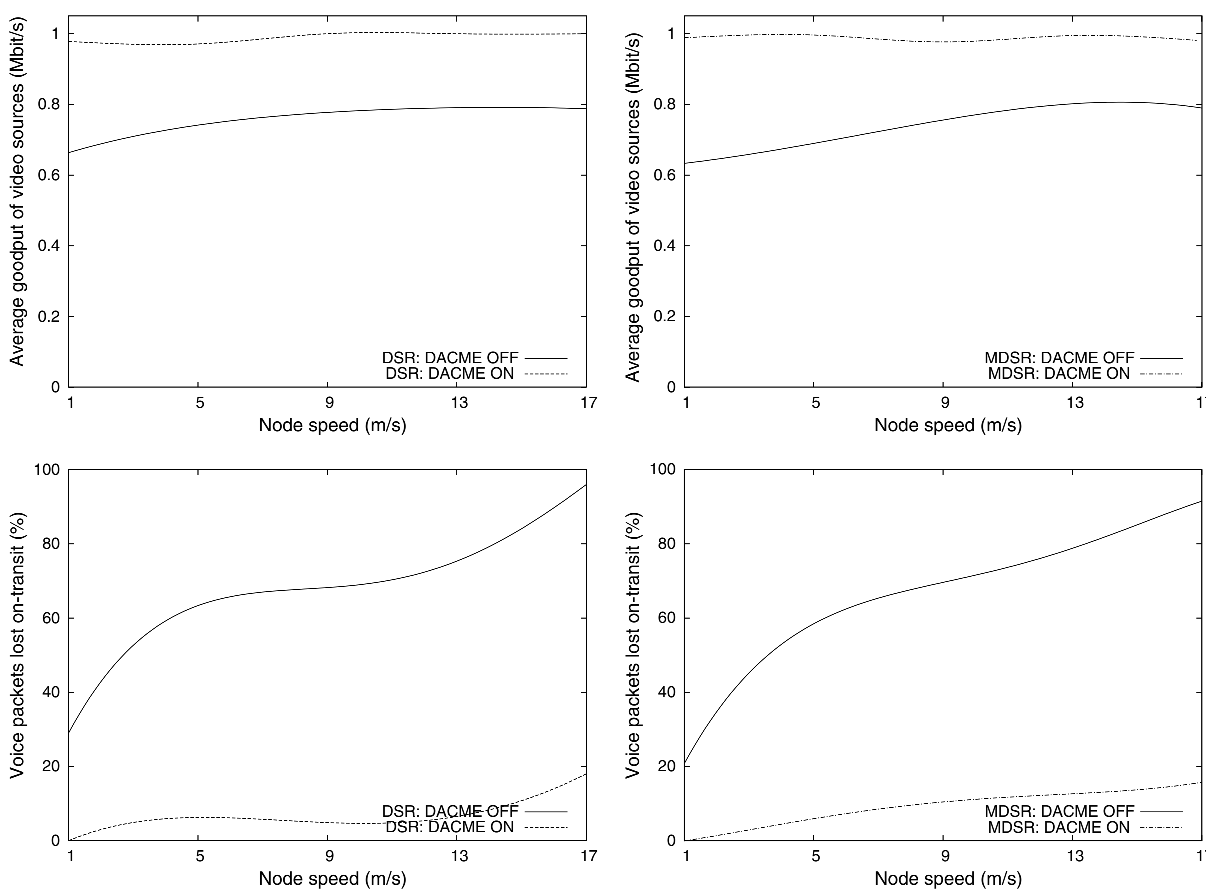

Fig. 13. Improvements on video goodput (top) and voice packet drops (bottom) by using DACME with DSR (left) and MDSR (right).

transmit, and when they are allowed to do so the throughput is maintained reasonably steady.

In terms of end-to-end delay Fig. 12 shows that, in a similar manner to what was observed in the previous section, the performance for DSR and MDSR with DACME relative to video traffic is similar, and clearly superior compared to the non-DACME results.

We can also see that introducing DACME provides much better performance to the voice flows, especially with MDSR where the end-to-end delay does not surpass 20 ms.

5.2. Performance under varying degrees of mobility

In this section we study the performance of DACME when varying node mobility; the speeds used in our tests were 1, 5, 9, 13 and 17 m/s. The purpose is to assess the effectiveness of DACME when the average route lifetime decreases. For this set of experiments we fix the value of the aggregate background traffic to moderate congestion (2.3 Mbit/s).

Fig. 13 shows the improvements in terms of video goodput and voice packets dropped when varying speed. We observe that DACME retains its effectiveness, even at very high node speeds.

Even though for the video traffic the difference remains constant, we notice that for voice traffic increasing node speed quickly decreases performance if DACME is not used, with a loss rate approaching 100% (collapse point). When node mobility is increased, routing overhead is also increases, which explains the correlation experienced between voice packet loss rate and speed.

In terms of video end-to-end delay, Fig. 14 shows that, in general, it increases with increasing node speed; this is caused by additional re-routing events. For voice traffic there is a different trend, being delay slightly reduced at higher speeds. This is due to a significant variation in terms of traffic blocking if DACME is used, or to an increased packet loss rate if DACME is turned off.

With respect to routing overhead, Fig. 15 shows that, as expected, it increases with increasing node speed. However, we again find that the use of DACME is effective at reducing routing overhead, as exposed in Section 5.1.

Finally, in terms of traffic acceptance rate, Fig. 16 shows that DACME offers similar admission rates for node speeds up to 13 m/s. Above that speed there is a clear decrease in terms of overall traffic admission, which is explained by a shortening of routes' lifetime.

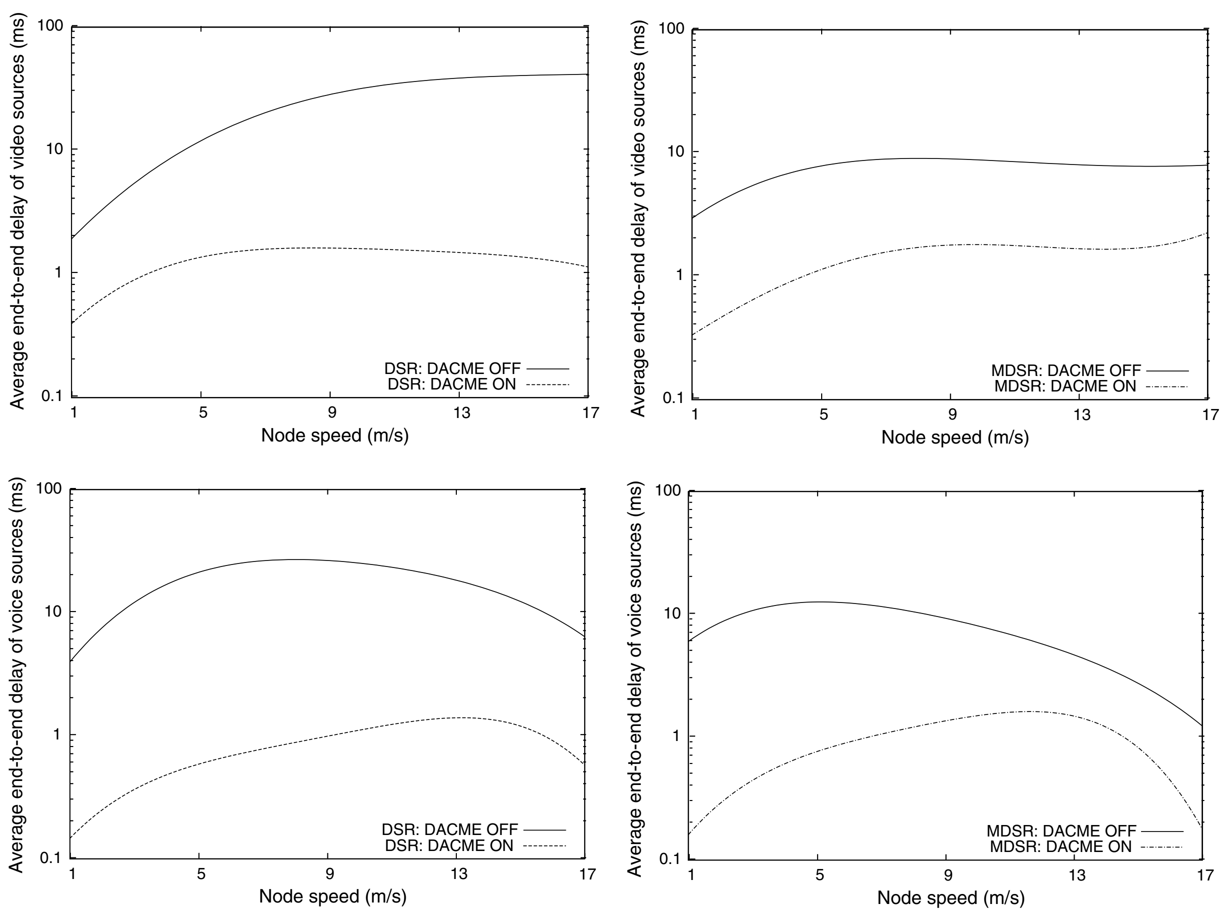

Fig. 14. Average end-to-end delay values for video (top) and voice (bottom) sources for DSR (left) and MDSR (right).

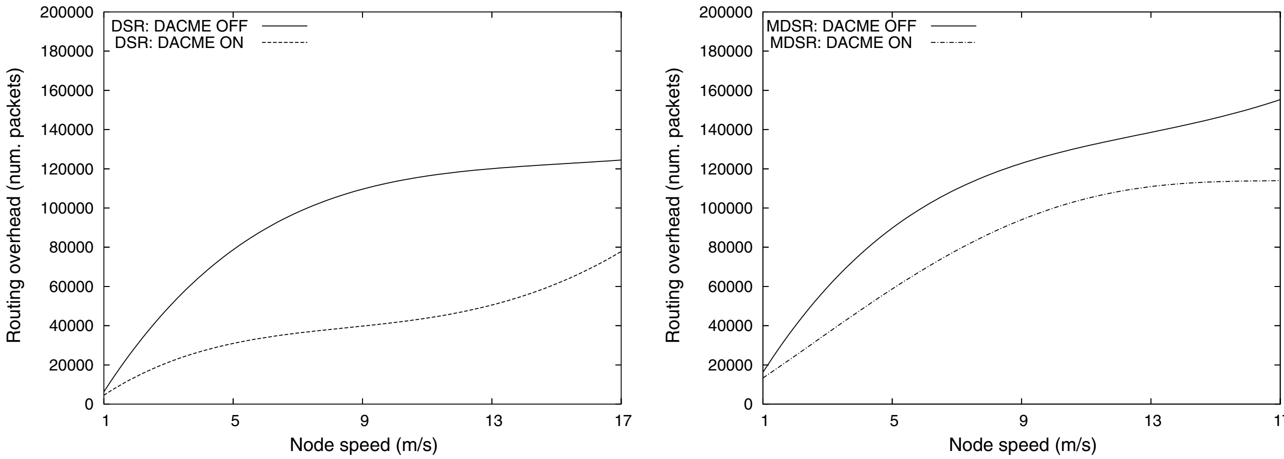

Fig. 15. Routing overhead for DSR (left) and MDSR (right).

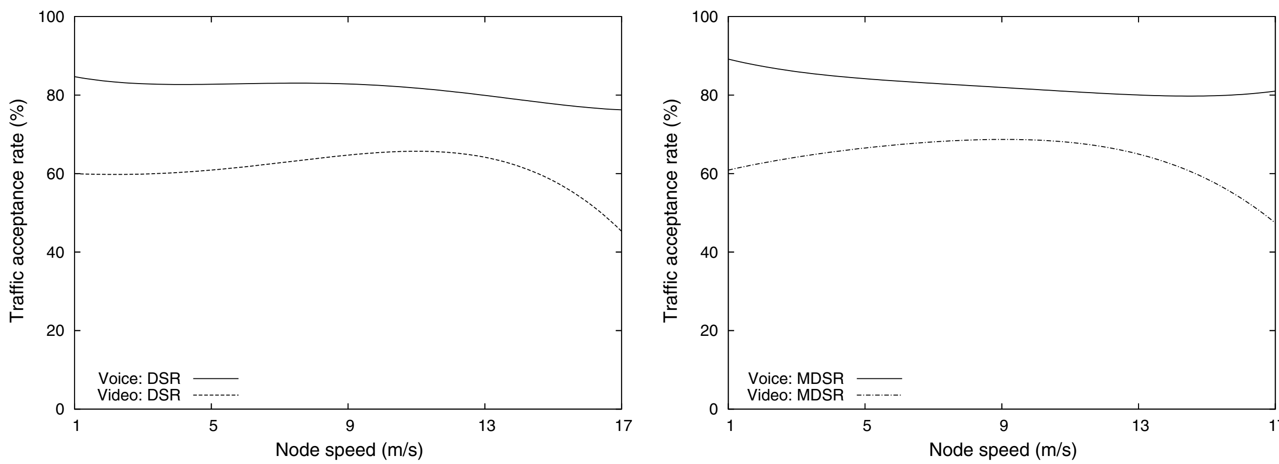

Fig. 16. Percentage of admitted traffic using both DACME versions at different congestion levels for DSR (left) and MDSR (right).

6. Conclusions and future work

We presented a novel QoS framework for MANET environments based on the use of the IEEE 802.11e technology, along with our novel admission control 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 multi-path 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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Carlos T. Calafate graduated with honors in Electrical and Computer Engineering at the University of Oporto (Portugal) in 2001. He received his Ph.D. degree in Computer Engineering from the Technical University of Valencia in 2006, where he works as an assistant professor since 2005. He is a member of the Computer Networks Group (GRC). His research interests include mobile and pervasive computing, security and QoS on wireless networks, as well as video coding and streaming.

Jose Oliver received the MS and PhD degrees in Computer Engineering from the Technical University of Valencia (UPV) in Spain, in 1998 and 2006, respectively. He is with the Department of Computer Engineering (DISCA) at UPV since 1999, where he holds a lecturer position gained by means of the "Programa Cantera" in 2001. Since then, he teaches Computer Networks and Multimedia Networks at the Faculty of Computer Science. His research interests include image and video coding and wireless transmission.

Juan Carlos Cano is an associate professor in the Department of Computer Engineering at the Technical University of Valencia (UPV) in Spain. He received the MSc and a Ph.D. degrees in Computer Science from the UPV in 1994 and 2002, respectively. Between 1995 and 97 he worked as a programming analyst at IBMs manufacturing division in Valencia. His current research interests include power aware routing protocols for mobile ad hoc networks and pervasive computing.

Pietro Manzoni is an associate professor of computer science at the Technical University of Valencia (SPAIN). He received the M.S. degree in Computer Science from the ''Università degli Studi'' of Milan (ITALY) in 1989 and the Ph.D. in Computer Science from the Polytechnic University of Milan (ITALY) in 1995. His research activity is related to wireless networks protocol design, modeling and implementation.

Manuel P. Malumbres Manuel Perez Malumbres received his B.S in Computer Science from the University of Oviedo (Spain) in 1986. In 1989 he joined to the Computer Engineering Departament (DISCA) at Technical University of Valencia (UPV), Spain, as an assistant professor. Then, he received the M.S. and Ph.D. degrees in Computer Science from UPV, at 1991 and 1996, respectively. In september 2005, he moved to Miguel Hernandez University holding the same position. His research and teaching activities are related to multimedia networking (audio/video coding and network delivery) and wireless technologies (MANETs and sensor networks).