QMMAC - New QoS Model with Admission Control for Mobile Ad hoc Networks

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Abstract
This paper deals with quality of service in mobile ad hoc networks. It aims at admission control schemes in this kind of networks. The state of the art is summed up and open problems are identified in this paper. Then, our proposed new QoS model for MANETs called QMMAC is presented. We provide the architecture of the model, its features and parameters. The paper also describes the process of fine-tuning models parameters. Finally, we provide an evaluation of proposed QoS model based on simulation experiments.

Categories and Subject Descriptors
C.2.1 [**Computer-Comunication Networks**]: Network Architecture and Design

Keywords
Quality of Service, Admission Control, Mobile Ad hoc Network, MANET, QoS Model

1. Introduction
The use of mobile devices and wireless technology in almost every area has grown rapidly in the last few years. Information and communication wireless networks have become ubiquitous. A special kind of these networks is mobile ad hoc network which does not need any fixed infrastructure and it is possible to establish and use it in almost any environment. This kind of wireless networks can configure, administer and control themselves. Any node in the network can communicate with any other node independently from other nodes in the network. The use of mobile ad hoc networks is in such environments where there is no central infrastructure or it is not trustworthy. They are used very often in the army, as any sensor networks or as any temporally created networks for conferences, special areas in industry, for animals monitoring, space research or underwater activities. The fact that two nodes can communicate even if they are mobile does not mean that all communication requirements are fulfilled. There are some requirements for quality of this communication and the communication has to follow some before-defined quality level. Then, the communication network can provide communication service or data transfer service and it has relevance to speak about quality of this service. Quality of service can be described by several quantitative and qualitative parameters from maximum end-to-end delay, minimal bandwidth, and transmission reliability to confidentiality, integrity and authenticity of transmitted data. Due to their specific features, mobile ad hoc networks can provide very low quality of service levels which is often required in various environments. This paper deals with quality of service assurance in mobile ad hoc networks and some chosen issues related to it. The paper is divided into six section. The first section provides an introduction into MANETs and QoS field. Then, MANETs and their features are descibed in Section 2. In the Section 3, we provided related work and the state of the art. Our proposed new QoS model for MANETs is presented in Section 4 and its evaluation can be find in Section 5. Finally, Sections 6 concludes this paper with final evaluation and future work describtion.

2. MANETs
Mobile ad hoc network (MANET) is a wireless network with no regards to physical or link layer protocol or technology, without any central control and infrastructure, established for some specific reason, often temporally with an ad hoc topology. Ad hoc topology means that the network topology is established without previous planning whereby network nodes can change their positions and move even during communication. Communication can be established among any nodes in the network via multi-hop basis. MANET can be defined also as a system of wireless network nodes which can be dynamically self-organised into any temporally network topologies [3]. The physical area in the environment where network nodes are distributed is called service area. Every node in the MANET network has hardware for receiving and also for transmitting data from/to wireless media. That means that every node needs to be not only a communication endpoint but also a router for other nodes. MANET can be connected to the Internet or to wired infrastructure by various network gateways or nodes working as a gateway.

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As stated above, MANETs have several specific features. Due to the mobility of nodes, the network topology changes in the time and also network and wireless media parameters change. It is necessary to state that MANETs are battery powered and therefore power consumption is very important. The main features of MANET networks which determine requirements for protocol design and various technologies for this kind of networks are as follows:

Dynamic network topology

Nodes can move and change their location. This feature has great impact to routing and in general routing information is not precise and current.

Bandwidth and end-to-end delay constraint

Bandwidth and end-to-end delay on particular links vary quite often. In comparison with wired networks, bandwidth is lower and it is facing to some issues related to interference and loss.

Power constraint

Network nodes are battery powered and therefore it is necessary to have in mind the power consumption with any activity.

Restricted physical security

Physical security in this kind of networks is much lower compared with wired networks. The biggest threats are eavesdropping, spoofing and denial of service attacks. On the other hand, there is an advantage of robustness and one-point failure in some cases due to distribute nature of MANETs.

3. Related work

Due to MANET features stated above, hard QoS assurance during the whole communication is very difficult issue and therefore the soft QoS is in use. In the case of soft QoS provisioning, not every requirement has to be fulfilled in some period of time. Conventional QoS models for wired network are not suitable for MANETs. They were designed for other network features. The main problems are scalability, restricted bandwidth and high overhead of classis QoS models and protocols which is not acceptable for nodes with limited resources. The first QoS model for MANET comes from [12] and it is called FQMM - Flexible QoS Model for MANET. It was designed with regards on specific features of small or medium-size MANETs with number of nodes below 50 and with network topology without any hierarchy. The word -flexible- means that particular architectural blocks of this model can be anyhow combined or removed. The model combines the advantages of data flows granularity from IntServ model and service differentiation from DiffServ model. The whole model is operating at network layer with close cooperation of MAC layer. It is divided into two planes; management and control plane and forwarding plane. Since FQMM is a combination of IntServ and Diffserv, it has also their disadvantages, namely the scalability of the model in MANET environment. It is necessary to state that this model is very theoretical and it has been not implemented in real use as a whole model due to its complexity. Nowadays, it is used as a reference QoS model for MANETs.

Another QoS model for MANETs is CLIASM (Cross Layer Interactions And Service Mapping). The main idea of this model is creation of shared database commonly used by all layers of network model. The database contains data from various protocols through the whole network stack together with information about QoS. The advantage of such a solution is that each layer has the same information about network parameters and available resources. As in the previous QoS model, nodes along the communication path are not involved in QoS provisioning which is done by source node completely including state information maintaining. According to some sources, undesirable interactions might be occurring and stability issues can arrive by real implementation of this model [6].

SWAN (Stateless Wireless Ad hoc Networks) is a simple QoS model based on distribution technique of transmission control, namely AIMD (Additive Increase Multiplicative Decrease) with service differentiation in the network. Network traffic is classified into two categories; real-time traffic and best-effort traffic. Best-effort traffic is shaped in order to provide desired resources to real-time traffic. For network traffic regulation, ECN (Explicit Congestion Notification is also used. A disadvantage of this model is the lack of signalisation and reservation protocol. The model is not very suitable for networks with higher percentage of real-time network traffic which might need several QoS levels [1], [16].

The main advantage of the next QoS model DEQA (Design of an Efficient QoS Architecture) is its scalability and reliability [10]. On the other hand, as the disadvantage can be unbalance between real-time network traffic and best-effort traffic in case of network congestion. The model consists of three parts; routing, call admission control and congestion control. Admission control is an important part of QoS provisioning in every type of network in general. The base form of admission control can be also a routing protocol oriented at QoS. If the particular communication path does not fulfil QoS requirements, communication request can be denied.

The admission control principles can be classified into several categories based on various criteria. One of them is if they are independent from routing protocol. Another one is the way how they store state information or routing technique. Admission control scheme called PMAC (Passive Measurement-based Approach to admission Control) [8] is based on end-to-end delay and packet loss parameters. Source node marks each packet of every new data flow with a sequence number and timestamp. Every new data flow is admitted at the beginning and destination node monitors network parameters carried in packet headers and compares them with packet receiving time. Based on these evaluations, it sends the information to source node whether admit or deny a particular data flow. Another approach independent from routing protocol but using all network nodes along the path is QPART (QoS Protocol for Ad-hoc Real-time Traffic) [14]. The basic idea is to admit all data flows with low priority and to increase the priority periodically based on the information from routing and MAC layer. The first packet of data flow carries information for all nodes along the communication path about QoS requirements. Other group of admission control principles are those which depend on routing protocols. The example is INORA (IN-band signalling and temporally-Ordered Routing Algorithm). It is a combination of routing protocol TORA and signalization scheme INSIGNIA. There exist many variations of AODV routing protocol with admission control feature like QoS AODV [7], ACSCQS [5] and AQOR [13]. The representatives of reactive routing schemes with admission control are CACP [15], [7] and ACRMP [4]. The big disadvantage of these admission control schemes is that admission control is very simple, not scalable and robust.

4. A new QoS model for MANETs

In this section, we describe our proposal of new QoS model with admission control for MANETs called QMMAC (QoS Model for Manets with Admission Control). Admission control is an important QoS tool together with QoS routing, reservation, queuing, congestion control and traffic classification. The main role of admission control is to admit or deny a new data flow into network based on available resources and data flow requirements. In order to make fair and correct decisions of admission control algorithms, it is necessary that admission control has accurate and current data about network parameters and available resources. In wired networks, there exist several admission control techniques which are working well but unfortunately they are not applicable for MANETs due to their specific features. Based on the results of the state of the art analysis, we proposed a new QoS model for MANETs which differs from the majority of current models, namely, in the need of model implementation in each network node. QMMAC has to be implemented only at communication endpoints and for other nodes along the path, it is transparent. Model uses the existing technology IEEE 802.11e as a link layer protocol which is capable to categorize network traffic into four classes and to provide them different QoS levels. One of the basic aims during the proposal was its simplicity and easy implementation into real MANET. We also required that admission control has the minimal overhead to network nodes along the path and multipath routing should be supported. Admission control should provide soft QoS and make decisions based on available bandwidth, end-to-end delay and jitter. We also required cross-layered approach which is according to [9] one of the basic requirements for successful implementation in real MANET networks. Model QMMAC has admission control based on network parameters gained from network evaluation process. It consists of generation of probe packets, thus it is active measurement approach. This approach is not new, it was used in [2] in wired networks but it is not applicable for MANETs due to nodes mobility, as showed in [1]. The basic scheme of QMMAC model is showed in the Figure 1. The whole model can be devided into three architectural blocks. The block of admission control decides about admitting or denying packet flows into network based on data coming from the block named Measurement of QoS parameters. Besides that, this block is responsible also for packet marking in ToS field according to application requirements. This marking is then transformed into IEEE 802.11e marking. The main role of this block is network parameters estimation by means of probe packets generation. This kind of data are stored in another architectonical block of this model named Information and statistical database. This block communicates directly with the application which registries through it in the admission control system and receives feedback about the current situation in the network. The registration of the application in the admission control system means data about source and destination IP address, sourced and destination port,

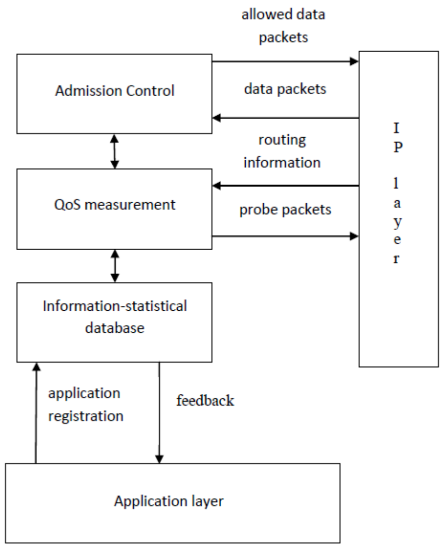

Figure 1: QMMAC architecture.

transport protocol and QoS requirements. This kind of information is stored in Information-statistical database with source port indexation. The classical admission control approaches are oriented at the beginning of the network flow and after admitting it, they do not monitor it any more. This approach is not suitable in MANETs due the mobility of the nodes. Therefore, it is necessary that admission control monitors some chosen network parameters periodically and evaluates the network possibility to provide desired resources to data flows. The network parameters measurement is done in several measurement cycles which consist of a set of probe packets and one response. In order to handle packet loss, the model contains a null response. This kind of response means that the particular measurement was not successful and it has to be repeated or inform source application.

With the regard on packet losses in the network, the threshold x was defined. This value determines the number of packets having sense to analyze and gain correct data. The threshold x is a percentage of all transmitted packets which should have to be received in order to gain a correct results.

4.1 Bandwidth estimation

The following approach is proposed for bandwidth estimation on communication path between source and destination node. Source node generates probe packets to destination node which then response with the information about available bandwidth on the path. Both nodes have a time counter in case of probe packets losses. In order to estimate bandwidth value correctly and accurately, it is necessary to use several measurement cycles. One cycle consists of a set of n probe packets and one response from destination node. After receiving all probe packets or after counter TD triggers, destination node will send a response in one packet with available bandwidth estimation based on the following:

$$c = \frac{S}{T}[b/s] \quad (1)$$

where c is measured bandwidth, S is probe packets length in bits and T represents the average time of receiving of particular probe packets, defined as:

$$T = \frac{t}{n-1}[s] \quad (2)$$

where t is time between receiving the first probe packet and the last probe packet in one particular measurement cycle or time until the counter triggers. The number of probe packet in one particular measurement cycles is n.

The packet lengths are usually in bytes, therefore we assume, S is in bytes. After combination of two previous equations, we have an estimation equation for bandwidth as follows

$$c = \frac{8S(n-1)}{t}[b/s] \quad (3)$$

We proposed two counters in the process of bandwidth estimation. The main reason of them is packet losses in wireless mobile environment and delay caused by network congestion. The counter TS in source node is used in case of loss or delay of response packet from a destination node. It should be set according to particular requirements and network parameters as well as application needs.

The counter TD in destination node prevents endless waiting for all probe packets in case of their loss or delay. That means, it assumes receiving only a subset of probe packets. Therefore it is important to tune the counter after receiving each probe packet. The value of this counter is tuned according to following relation

$$T_d = n_j \frac{t_i - t_1}{n_i - 1} + \epsilon[b/s] \quad (4)$$

Where t_1 is the time of receiving the first probe packet, t_i is the time of receiving the current probe packet and n_i represents the number of received probe packets, n_j is the number of probe packets which have not been received yet and ϵ is an experimental constant for fine tuning of the counter. Based on the information about available bandwidth estimation, the source node decides if it admits a data flow or not, and then informs the application about current network status. In case that is not clear if admit or deny a particular data flow, even after maximal number of measurement cycles, the previous state of data flow should be kept due to network stability. That means that active connections would be still active and new data flows requesting communication would be blocked.

4.2 End-to-end delay estimation

The end-to-end delay estimation is very similar to traditional PING protocol working on request-response principle with RTT (Round Trip Time) estimation. This principle assumes that the communication path is symmetric with the same network parameters in both ways.

End-to-end delay estimation in QMMAC is based on probe packet generating and response receiving. This is done in several measurement cycles. The probe packet and response packet need to be in the same priority class and should have the same lengths. Unlike probe packet during bandwidth estimation, these probe packets have to be in the same priority class as the application because of accurateness and correctness of measurement.

4.3 Jitter estimation

Jitter estimation in QMMAC is very similar then estimation of this network parameter in protocol RTP. Source node generates probe packets with the same length and with the same rate as the application data packets. The probe packets are also in the same priority class as the application. Source node informs directly destination node about data packet transmission rate. Destination node then estimates the average and standard deviation of measured jitter and sends these values to source node. The jitter estimation process is done only if the application is blocked and it is done after bandwidth and end-to-end delay estimation, if none of them denied the particular data flow. In case that data flow is already admitted, it is not necessary to estimate jitter via active probe packet generating. Destination node is capable to estimate jitter from current network traffic and send this information to source node.

4.4 QMMAC model within network protocol stack

One of the main requirements within new QoS model proposal was the cross-layered approach. The interaction of protocol stack layers is described in this section.

QMMAC and application layer

Application requesting some QoS requirements has to register in QMMAC model, namely in admission control block. The aim of application registration is obtaining of important data about particular data flow and desired QoS requirements. Then, QMMAC is capable to communicate with application in order to get feedback about the current network status and admission control block activities. Based on this feedback, the application can modify some requirements or decide to communicate later. The admission control block can group some applications based on their QoS requirements and also based on the destination IP address and this way decrease the number of measurement cycles and probe packets generated. When the communication ends, the application will unregister from admission control block. If not, there is also a counter of data flow inactivity in Information-statistical block of QMMAC which unregisters the application automatically.

QMMAC and network layer

The interaction of admission control and network layer is possible in various ways. Admission control can benefit from routing information. For instance, it can use the information about communication paths and in case that no path for particular destination exists or it is unreachable, it can avoid sending probe packets to it. QMMAC model cooperates very closely with routing layer. It uses AODV routing protocol. The cooperation is mainly in the following two aspects. The first one is periodical monitoring of incoming routing packets and if RREP packet is detected, it is check whether it is related to destination IP address registered in QMMAC. If so, then measurement cycle starts, also if it was planned later. This way, QMMAC can estimate the communication path very quickly after it becomes available. The second aspect of AODV and QMMAC cooperation is worth in situation when probe packets were generated and source node waits for a response which does not arrive within the defined time period and the particular counter triggers. Normally, admission control would consider this path unreachable. However, if RREP message is received within the waiting period, probe packets could be generated again in order to determine if communication path becomes again available within short time period.

Table 1: QMMAC packet format

Type	Sequence number	ID	Last ID	Data

QMMAC and MAC layer

QMMAC model uses IEEE 802.11e technology as a MAC layer protocol. Probe packets should be transmitted with ToS marking in IP header which is then transformed into one of four priority classes in IEEE 802.11e. Probe packets during bandwidth estimation are in Video category and probe packets during end-to-end delay and jitter estimation are in the same priority category as the application requiring QoS.

4.5 QMMAC packets format

In order to exchange information and probe and response packets transmission, the packet format presented in the Table 1. was proposed. This packet header is encapsulated in UDP protocol and then in IP protocol. The header has four bytes. The field Type defines the type of the format: BW-P -probe packet for bandwidth estimation BW-R - probe packet for bandwidth estimation - response DL-P - probe packet for end-to-end delay estimation DL-R - probe packet for end-to-end delay estimation - response JT-P - probe packet for jitter estimation JT-R - probe packet for jitter estimation - response Sequence number represents 8 bit number identifying particular measurement cycle. The field ID is an 8 bit number which identifies a packet within one measurement cycle. Last ID field is also an 8 bit number which is used by destination node for estimation of not received packets. The length of data field is kept on system resources and it is used for various data values transmission or other needed data.

4.6 Fine-tuning of QMMAC parameters

In order to find the optimal QoS model parameters, we did simulations in network simulator ns-2 version 2.32. Simulations were done with IEEE 802.11e implementation from [11]. The main QMMAC parameters are as follows: n - number of probe packets in a particular measurement cycle m - number of measurement cycles Ts - counter in source node Td - counter in destination node x - a percentage of all generated probe packets which mean a threshold for null response sending All simulation experiments were done on a MANET model containing four source nodes, four destination nodes and three intermediate nodes. The average hop-count in the network was 4. Based on simulations, we found out the optimal parameters of the proposed model summed up in the Table 2.

5. QMMAC model evaluation

We evaluated the proposed new QoS model called QMMAC with its parameters on two main scenarios; static and dynamic. Static scenario was used for basic model evaluation as well as its scalability. In dynamic scenario the nodes mobility played an important role. The aim of simulations was mainly to evaluate the whole model architecture, choice and suitability of proposed parameters and their recommended values. We compared our model with an approach without admission control.

5.1 Static scenario

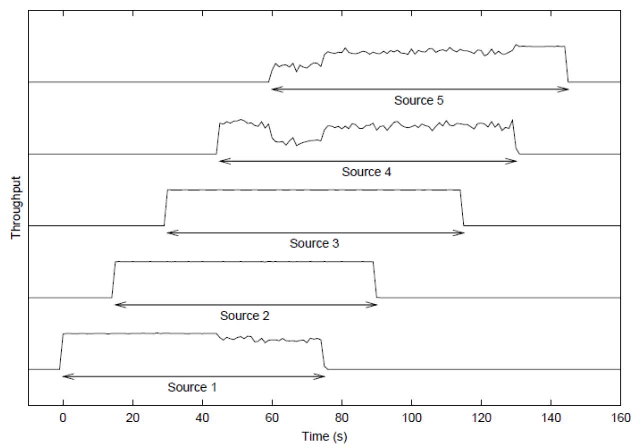

Figure 2: Throughput of data flows without admission control.

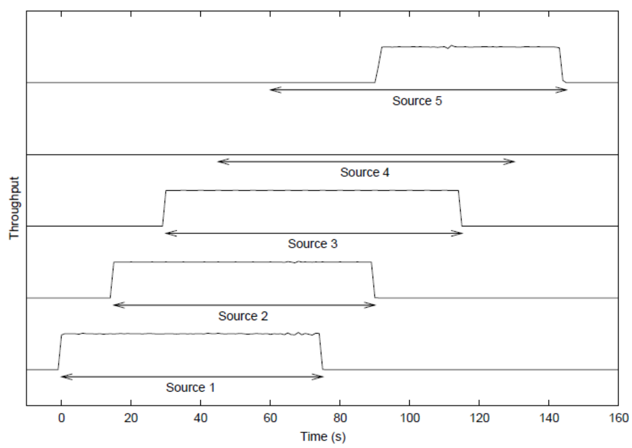

Figure 3: Throughput of data flows with admission control.

The simulation parameters for static scenario were as follows. The static scenario means that node mobility was not present, all network nodes were static and there was no dynamic routing protocol in place. In the static environment, we could evaluate the basic model behaviour and its main parameters.

Physical network area 1900 x 400 m

Mobility model none

MAC layer IEEE 802.11g / IEEE 802.11e

Node communication radius 250 m

The average hop-coun 4

Nodes position random

Routing static

Data traffic was simulated as 5 packet flows in Video priority class with transmission rate CBR 1 Mb/s. Background traffic was simulated as 4 packet flows with transmission rate 50 packets per second and each flow in different priority class. The length of data packets as well as background

Table 2: QMMAC parameters and its values

Parameter	Description	Value
n	number of probe packets in a particular measurement cycle	10
m	number of measurement cycles	5
T_s	counter in source node	500ms
T_d	counter in destination node	$T_d = n_j \frac{t_i - t_1}{n_i - 1} + \epsilon$
x	threshold of received probe packets for null response sending	50%
k	Number of probe packets for end-to-end delay estimation	4
t	time of jitter measurement	250ms

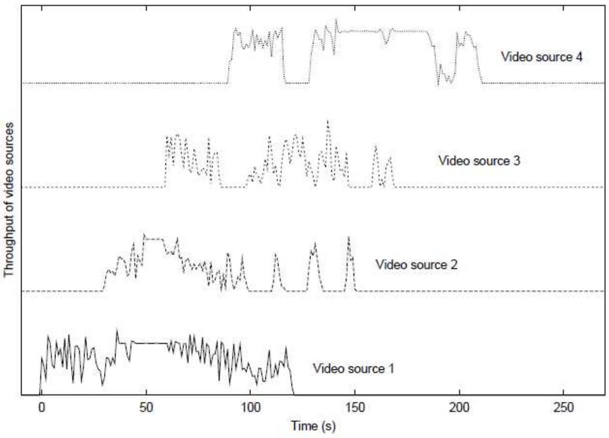

Figure 4: Throughput of data flows in Video priority class without admission control.

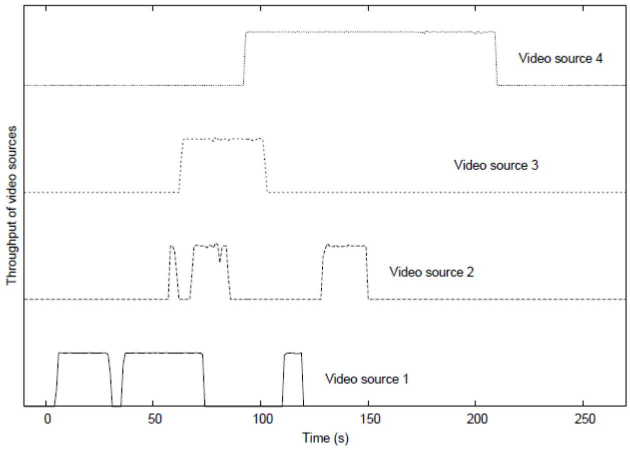

Figure 5: Throughput of data flows in Video priority class with admission control.

packet was 512 bytes. The first data flow started immediately and others were added in 15 seconds time steps. They were also finished in similar way. Throughput of data flows is illustrated in the Figure 2 and 3.

Simulations showed that if admission control was not in place, data flows 2 and 3 used the available bandwidth and flows 1,4,5 were degraded. The result is that there are data flows in the network whose throughput is not at desired level and QoS requirements are not fulfilled. Simulations with admission control showed that data flow 4 was not admitted in the network because of resources unavailability. For instance, data flow 5 is admitted only after data flow 2 ends. This behaviour of our proposed model proved its functionality and capability of quick reaction on dynamic network conditions.

5.2 Dynamic scenario

Dynamic scenarios were simulated with the same set of simulation parameters. Only the parameters stated below were modified. The dynamic scenario presents the real mobile ad hoc networks conditions, mainly random node mobility and dynamic routing approach.Background traffic was simulated by 4 packet flows with FTP application protocol. Routing traffic was in Voice priority class, 4 packet flows in Video priority class and 3 packet flows in Voice priority class. We did each simulation in different environment. We defined three levels of network congestion; low level congestion with background traffic 0.65 Mb/s, medium level with 2, 3 Mb/s and high level with 6.5 Mb/s. The following parametes were modifyied against static scenario:

Mobility model Random Waypoint Model

Nodes velocity 5 m/s

Routing protocols AODV, DSR, MDSR

As an example, we can illustrate the effectiveness of proposed model on the simulation experiment with high network congestion. In the situation without admission control, none of data flows is satisfied. With admission control data flows achieved desired bandwidth even they are often blocked as ilustrated in the Figure 4 and 5. In order to evaluate proposed QMMAC model for applications with end-to-end delay requirements, we did also various simulations. The network congestion in this type of experiments was generated by background traffic with 2,3 Mb/s. We defined maximum values of end-to-end delay from 0,1 ms to 100 ms. The Figure 6 illustrates the behaviour of end-to-end delay in Video priority class. Finally, we simulated data flows requiring end-to-end delay to be at a fixed value and also they have some jitter requirements. Fixed delay was set at the value of 10 ms and jitter could vary from 0,1 ms to 10 ms.

The Figure 7 documents the ratio of admitted network traffic in Video priority class which is under the desired jitter value. As it can be seen, with higher desired jitter value the ratio is increasing.

Based on all simulation experiments, we can argue that our proposed QMMAC model is effective and we evaluated its features and proposed parameters. Static and dynamic simulations proved that QMMAC model can save network resources by blocking data flows which QoS re-

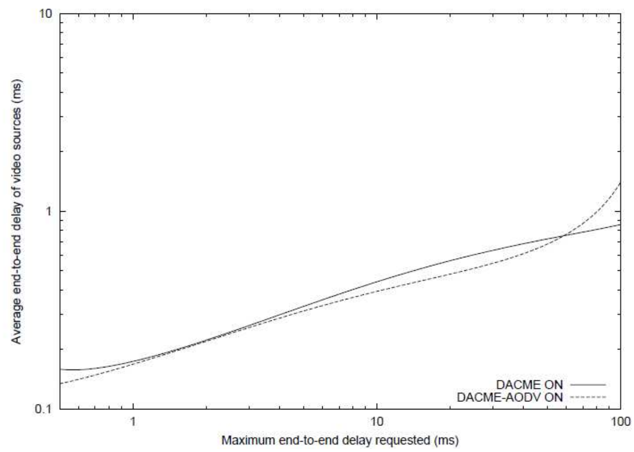

Figure 6: The average end-to-end delay in Video priority class.

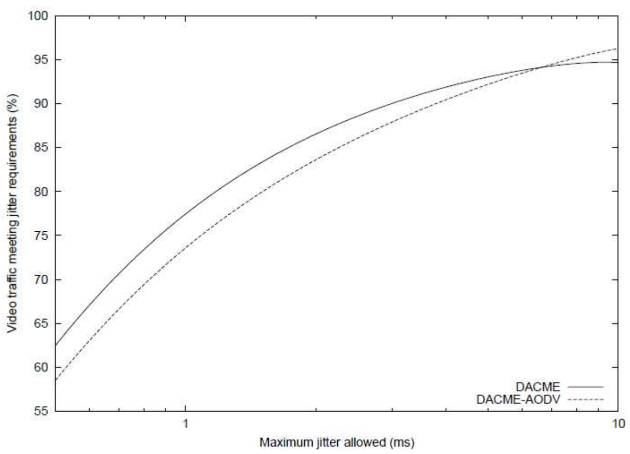

Figure 7: The ratio of admitted traffic in Video priority class.

quirements cannot be satisfied currently. Based on simulations, we find out the overhead of the model is between 30 and 60 kb/s and with jitter constrained applications it is about 120 kb/s.

6. Conclusions

In this paper, we presented our proposed new QoS model for MANETs called QMMAC. We described the architecture of this model, its main features and advantages. Based on simulations, we provided the overview of bandwidth, end-to-end delay and jitter estimation. After that, the process of recommended parameters of the model QMMAC was stated. According to the results of simulations and their evaluations, we can argue that our proposed model is stable, effective and scalable in the environment of small or medium-sized MANET. In the future, we would like to focus on the cooperation between QMMAC and application layer within a network protocol stack.

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