Towards Absolute End-to-End QoS in Ad Hoc Networks

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Abstract— **In this paper we propose a new model for providing QoS guarantees to real time multimedia applications in mobile ad hoc networks. Our model assures equal delay for each packet at every hop in the path, and handles network congestion through the use of call admission control and congestion control mechanisms. The effectiveness of our proposed solution in meeting desired QoS differentiation at a specific node and from end-to-end are assessed by simulation using a queueing network model implemented in QNAP. The experiments results show that our proposed solution provides consistent proportional differentiation for any service class and validates our claim even under bursty traffic and fading channel conditions.**

I. INTRODUCTION

A mobile Ad Hoc network (MANET [1]) is a collection of autonomous mobile hosts, where each one is equipped with wireless card that makes it able to communicate with any other host, directly if this last is in the same receiving zone, or indirectly through intermediate hosts that forward packets towards the required destination.

With the evolution of wireless communications and the emergence of diversified multimedia technologies, quality of service in ad hoc networks became an area of great interest. Besides existing problems for QoS in IP networks, MANETs impose new constraints due to the dynamic nature and energy constraint of each host, in addition to the shared distributed medium access with variable link capacity.

A lot of research has been done in routing area [1], [2], [3], [4], [5], [6], [7], and today routing protocols are considered mature enough to face energy constraints and a frequently changing network topology caused by mobility (e.g., DSR [2], [6], AODV [3], [6], etc.). Many QoS aware routing protocols that claim to provide a partial (or complete) solution to QoS routing problems have appeared consequently, e.g. QoS-AODV [4], MP-DSR [5], ASAP [8], CEDAR [9].

The Integrated services (IntServ) [10] and the differentiated services (DiffServ) [11] are the two principal architectures proposed to provide QoS in wired networks. While the IntServ approach achieves end-to-end services guarantees through per-flow resources reservations, the DiffServ focuses on traffic aggregates and provides more scalable architecture. DiffServ does not require any per-flow admission control or signaling, and routers do not maintain any per-flow state information. Routers only need to implement a priority scheduling and buffering mechanism, in order to serve packets according to specified fields in their headers.

The migration of these architectures to MANETs is proved to be inconsistent with the characteristics of these networks [12], [13]. Many researches have been based on these concepts and the mitigation of their impediments to make them suitable with the characteristics of MANETs, like INSIGNA [14], FQMM [15], and SWAN [16].

Taking into account bandwidth variation and routes change over time, QoS mechanisms that require explicit resource reservation to provide absolute QoS guarantee are not appropriate for ad hoc networks. However, with battery driven, interferences and mobility of each host, it is useless to reserve resources in order to guarantee worst cases QoS parameters, if we can guarantee neither the lifetime nor the duration of these resources. The relayed packets by the node at the extremity of a broken link will be inevitably lost. For these reasons, resources reservations techniques are not adequate with the characteristics of ad hoc networks, and we turn our attention to provide soft proportional QoS using differentiation architecture.

In the other hand, DiffServ aggregates flows in a set of classes and provides per-hop differentiation at each host. The correctness of its behavior is based at resource provisioning, and it does not define any scheme for taking corrective actions when congestion occurs. This is why a static DiffServ model is not suitable for ad hoc network. Therefore, it is imperative to use some kind of feedback as a measure of the states of the network to dynamically regulate the class of traffic with respect to the perceived and required QoS.

The proportional Differentiated Service (PDS) model aims to achieve better performance for high priority class relatively to low priority class within fixed pre-specified quality spacing [17], [18]. PDS classifies flows into N classes, where class i gets better proportional performance than class $i-1$. This proportionality is achieved through the use of a scheduling mechanism able to provide the pre-specified proportionality spacing between classes with respect to some QoS parameters. The most important idea of PDS is that even the actual quality of each class will change with network load, the spacing ratio between classes will remain constant.

Our proposed solution to provide end-to-end guarantee for real time traffic in ad hoc network is based on extending PDS model by the use of: Call Admission Control (CAC), Congestion Control (CC), bandwidth estimator and a slight modification to the static initialization mechanism of IEEE

802.11e, through the use of congestion window adaptor. The qualitative and quantitative study of our scheme is conducted by simulation based on a formal description expressed through a queueing network model in QNAP.

The rest of this paper is organized as follows. Section II gives a brief introduction to the PDS model with the impediments that prevent its use in ad hoc networks. Section III presents our proposed model with the description of the tasks that must be accomplished by each component. Section IV is devoted to the performance evaluation and analysis. Finally, section V concludes the paper with a summary of the results and future directions.

II. THE PROPORTIONAL DIFFERENTIATION SERVICE MODEL AND PROPERTIES

In proportional differentiation model ([17], [19], [20]), flows are grouped into N classes with service quality of class i is better than class $i-1$ for $1 \leq i \leq N$. The main objective of PDS model is to provide a relative proportional QoS between traffic classes, e.g. PDD (proportional delay differentiation) states that the average delay examined by classes should be proportional to some predefined differentiation parameters:

$$\frac{d_i(t,t+\tau)}{d_j(t,t+\tau)} = \frac{\delta_i}{\delta_j}, \forall\, i \neq j \; and \; i,j \in \{1,2,\ldots,N\} \qquad (1)$$

The class parameters δ_i, δ_j are the pre-specified differentiation parameters for classes i and j respectively, and they are ordered in manner that higher classes provide lower delays, i.e., $1 = \delta_1 > \delta_2 > \ldots > \delta_N > 0$. $d_i(t, t+\tau)$, $d_j(t, t+\tau)$ are the average delays for classes i and j in the interval $[t,\ t+\tau]$.

Many schedulers have been appeared to achieve this proportionality, e.g. WTP [17], PAD [20] and HPD [17]. In this paper, we will use Waiting Time Priority (WTP) scheduler to achieve required proportionality, but any other proportional scheduler may be used instead. WTP calculates the waiting time for each of head of line packet as $w_p(t) = t - t_{arrival}$ in different queues, and chooses the packet with the higher associated priority given by the following rules:

$$p_i(t) = \frac{w_i^p(t)}{\delta_i} = \frac{t - t_{arrival}}{\delta_i}$$

$$ser\_p(t) = \arg_{i=1\ldots N} \max(p_i(t))$$

With N is the set of all backlogged classes. The arrival process of real traffic usually follows continuous distributions probabilities, where the $Pr($2 packets arrive at the same instant) is zero and thus ensures the impossibility of two arrivals at the same instants.

The different classes must have equal waiting time at the same node in order to make the required proportionality between classes hold, e.g. transmitted packets of class i and j at time t_1 and t_2 must have:

$$\frac{w_i(t_1)}{\delta_i} = \frac{w_j(t_2)}{\delta_j} \qquad \forall i,j \in \{1,2,\ldots,N\}$$

While this mechanism is suitable for wired networks, it is still desirable to migrate this model into the wireless domain. Due to fact that WTP is a centralized scheduling scheme, it needs to know the waiting times of all packets before deciding which one to transmit at time t. This is trivial in IP network, where all packets waiting to be scheduled originate from the same router. In contrast, with the distributed access mechanism in ad hoc networks (CSMA/CA used in IEEE 802.11[21]), WTP can not achieve proportionality between classes at the same node, because of the additional random probabilistic waiting time due to contention resolution. Therefore, frames at the MAC layer in ad hoc network, wait for an additional random time before transmission, and thus render PDS model inefficient with these kinds of networks. This additional random time may cause priority reversal at transmission instant, where the frame may no longer be the corresponding one to the paquet with the highest priority. For clarification, if packet $P_{C=2}$ received at the MAC layer at time t_1, it will not be transmitted immediately but after a discrete uniformly distributed random time variable. At transmission time $t_{tx} = t_2$, this packet may no longer having the largest priority $p_i(t)$ as shows figure 1.

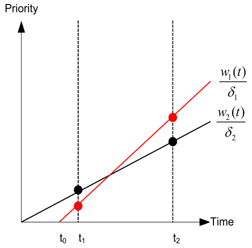


Fig. 1. Priority reversal.

In order to provide proportionality, we use the Enhanced Distributed Coordination Function (EDCF) in IEEE 802.11e [22], which extends IEEE 802.11 DCF with the introduction of different access categories by the use of distinct Arbitration Inter Frame Spaces ($AIFS_i$) and distinct initial contention window ($CW_{i,min}$) for different classes. We will exploit this technology with the Markov analysis given in [24], to provide the required differentiation by the introduction of some modification to the static initialization mechanism used in EDCF.

III. SPECIFICATION OF OUR PROPOSED MODEL

Our proposed model to provide end-to-end differentiation between classes along the same path is constructed from many mechanisms: Call Admission Control (CAC), Dynamic Class Selection (DCS), Waiting Time Priority (WTP), IEEE 802.11e, Congestion Window adaptor (CW), Bandwidth Estimator (BE) and Congestion Control (CC) as shown in figure 2.

The proposed model is based at WTP, IEEE 802.11e and CW adaptor to provide proportionality between classes as we explain in next sub-section. Other components like DCS, CAC, CC and BE are used to prevent saturation of the networks, and provide adaptation mechanisms with variable bandwidth channel. The proposed model works as follows: a delay sensitive application sends its maximum supported delay and tolerated jitter to the DCS, which communicates these information to

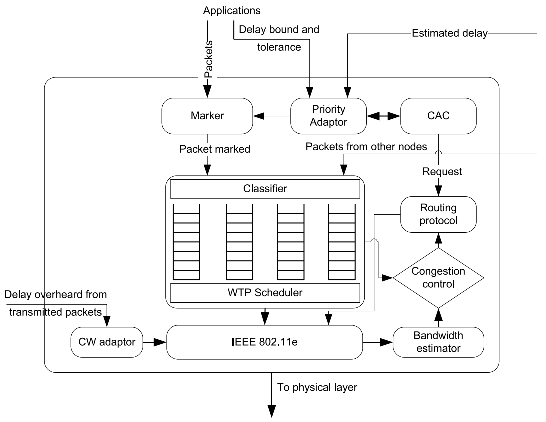


Fig. 2. Proposed model.

CAC. This last sends a request to the reactive routing protocol in order to find a route toward the specified destination, and trigger a timer to determine the end-to-end delay after the reception of route reply packet ($D_{e2e} = \frac{Timer}{2}$). Route request packet is sent with the highest priority N, in order to check the ability of the network to provide the specified delay. If estimated delay is larger than the application requirement, than the CAC refuses the connection and the sender application is informed to decrease the QoS requirement of its flow or to defer. In this way, we provide some guarantee for accepted flows in the network. On the other hand, if the estimated delay is smaller than the required, CAC sends a notification to the DCS that contains the estimated delay. However, the admission control is realized only before the new flow starts and its impact at existing flows is difficult to be accurately predicted with the absence of flows information at intermediates nodes and the violation of the conservation laws of WTP scheduler by the environment. Therefore, DCS mechanism tries to minimize the impact of newly admitted flows and provides adaptation to the existing real-time flows with network load by increasing their priorities according to perceived/required end-to-end delay. Furthermore, even if the new flow passes admission control, and the DCS increases the priorities of existing flows, there is no guarantee for enough resources for all flows. Therefore, congestion may still occurs and some flows must be rejected to maintain the guarantees made for realtime flows. A bandwidth estimator is used to estimate the idle channel time and to notify the network load status to the congestion control mechanism that triggers the corresponding actions to prevent network congestion.

A. IEEE 802.11e with Contention Window Adaptor

In ad hoc networks, nodes share the same medium with a decentralized scheduling scheme such as DCF [21] and its extension EDCF [22] for supporting delay differentiation by the use of four access categories (AC_i) representing four virtual DCF stations. Basically, EDCF uses different initial parameters ($AIFS_i$, $CW_{i,min}$ and $CW_{i,max}$ as shown in figure3) for different AC_i, instead of single $DIFS$, CW_{min}, and CW_{max} values as in DCF. In summary, EDCF works as follows: after a virtual station AC_i senses the channel idle for time period equal to $AIFS_i$, it generates a random backoff timer value before transmitting $BT_i = random(0, CW_{i,j}) \times aSlotTime$, where $random()$ is a pseudo random uniformly distributed from $[0, CW_{i,j}]$, and $aSlotTime$ is a very small time period. The backoff timer is decremented ($BT_{i,new} = BT_{i,old} - 1$) as long as the channel is sensed idle for $aSlotTime$, and freezed when a transmission is detected on the channel, then reactivated when the channel is sensed idle again for more than $AIFS_i$. The AC_i transmits when the backoff timer BT_i reaches zero. The initial contention window of class i is $CW_{i,j} = CW_{i,min} = 2^{i+3} - 1$ at the first attempt, and after each unsuccessful transmission, $CW_{i,j}$ is increased exponentially by a factor 2 up to a maximum value $CW_{i,max}$ as shown in equation 2.

$$CW_{i,j} = \left\{ \begin{array}{ll} 2^j CW_{i,0} & 0 \leq j \leq m \\ 2^m CW_{i,0} & m \leq j \leq R \end{array} \right\} \tag{2}$$

With R is the retransmission limit at the MAC layer and it is equal to 7 in both DCF and EDCF, and j denotes the number of unsuccessful transmission. After a successful transmission, $CW_{i,j}$ will be rest to $CW_{i,min}$. Basically, the smaller $AIFS_i$, $CW_{i,\min}$ and $CW_{i,max}$, the shorter the channel average access delay for the corresponding priority, and hence this priority obtains more capacity. However, the probability of collisions increases when operating with smaller $CW_{i,min}$. As [23] shows through simulations, EDCF performs poorly when the medium is highly loaded. This is due to the high collision rate and wasted idle slots caused by backoff in each contention cycle. EDCF service differentiation is qualitative and does provide any specific delay assurances between classes. Consequently, we study the influence of control parameters ($CW_{i,min}$, $CW_{i,max}$, $AIFS_i$, etc.) that affect the delay difference between classes. Therefore, we search the relationship between delays constraints and $CW_{i,min}$ for providing consistent differentiation.

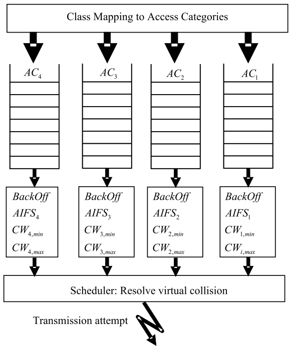


Fig. 3. Four access categories (ACs) for EDCF.

Bianchi in [24] presents a Markov chain model for analyzing the saturation throughput in IEEE 802.11. By analyzing the chain as it was proposed in [25] for IEEE 802.11e, we get all required value for average transmitting delay experienced by each AC_i:

$$D_i = \sum_{j=1}^{R} P_{i,j} T_{i,j}$$

where $P_{i,j}$ is the probability that a node i transmits the frame at the j^{th} backoff stage, and $T_{i,j}$ is its average delay. These parameters are given in [26], with:

$$P_{i,j} = (1-p_i)(p_i)^j \qquad 0 \leq j \leq R.$$

$$T_{i,j} = AIFS_i + \frac{S_i}{2}.\sum_{l=0}^{j} CW_{i,l} + j.p_i.T_{i,c} \qquad 0 \leq j \leq R.$$

Consequently, the ratio of average delays of adjacent classes can be written as:

$$\frac{D_{i+1}}{D_i} = \frac{\sum\limits_{j=0}^{R=7} P_{i+1,j} T_{i+1,j}}{\sum\limits_{j=0}^{R=7} P_{i,j} T_{i,j}} =$$

$$\frac{\sum_{j=0}^{R=7} (AIFS_{i+1} + \frac{S_{i+1}}{2} \sum_{b=0}^{j} CW_{i+1,b} + j.p_{i+1}.T_{i+1,c}).P_{i+1,j}}{\sum_{j=0}^{R=7} (AIFS_i + \frac{S_i}{2} \sum_{b=0}^{j} CW_{i,b} + j.p_i.T_{i,c}).P_{i,j}}$$

As shows previous formulas, the control parameters that affect the delay experienced by a packet are: $AIFS_i$, R, and $CW_{i,min}$. Numerically, p_i is approximately the same for all classes, $AIFS_i$ and $j.p_i.T_{i,c}$ are smaller than the only significant parameter $CW_{i,b}$, as proves the study in [25].

$$\frac{D_{i+1}}{D_i} \approx \frac{\sum\limits_{j=0}^{R=7} \left(\frac{S_{i+1}}{2} \sum\limits_{b=0}^{j} CW_{i+1,b} \right)}{\sum\limits_{j=0}^{R=7} \left(\frac{S_i}{2} \sum\limits_{b=0}^{j} CW_{i,b} \right)} \approx \frac{CW_{i+1,0}}{CW_{i,0}} \qquad (3)$$

Therefore, delay proportionality can hold between classes at the same nodes and consequently from end-to-end, because the packet end-to-end delay equals to the sum of all per-hop delays along its path. On the other hand, we turn our attention to provide fair delay for each class at different nodes along the path using CW adaptor. We want to provide an extension to equation 1, to make it hold along every node in the path, according to:

$$\frac{d_i^p(t, t+\tau)}{d_j^q(t, t+\tau)} = \frac{\delta_i}{\delta_j}, \quad \forall\, i \neq j \quad and \quad \forall\, p \neq q$$

The superscripts p and q represent the *ids* of two nodes along the path. Equal time delay between contending nodes can be achieved through dynamic adaptive contention window adjustment as follows:

$$CW_i^p(t_k) = CW_i^p(t_{k-1}) \times (1 + \eta \frac{\bar{d}_{Net}^p(t_{k-1}) - \bar{d}_i^p(t_{k-1})}{\bar{d}_{Net}^p(t_{k-1})})$$

with $\overline{w_i^p}(t) = \frac{t_{tx} - t_{arrival}}{\delta_i} = \frac{W_{packet}^p}{\delta_i}$ is the normalized delay experienced by a packet at node p, and $\overline{d_i^p}(t_k)$ is the average of this normalized delay calculated as follows:

$$\overline{d_i^p}(t_k) = \alpha \overline{w_i^p}(t_k) + (1-\alpha)\overline{d_i^p}(t_{k-1})$$

$$\overline{d_N^p}(t_k) = \delta \overline{d_i^p}(t_k) + \beta \overline{d_N^q}(t_k) + (1 - \delta - \beta)\overline{d_N^p}(t_k)$$

$\bar{d}_N^p(t_k)$ denotes the estimated normalized delay of the networks at node p and η is a small positive constant. Each node must estimates its average waiting time $\overline{d_i^p}(t)$ after the transmission of each packet using the RTT average formula, and the average waiting time of the networks $\overline{d_N^p}(t)$ after overhearing of a packet transmitted in its contending zone. Afterward, the node must adjust its minimum contention window accordingly, by comparing the average delay of its transmitting packets with the networks average delay estimated from collected data from other nodes in the same reception zone. To protect proportionality at the same node, congestion window adaptor updates initial CW for high priority class after its successful transmission of a frame and updates the initial value for others classes in a local proportional manner.

B. Call Admission Control

The goal of the CAC is to ensure the total requirements of realtime flows are smaller than the network capacity. However, if the total admitted realtime flows exceed the capacity of the network, no scheduling algorithm can guarantee the QoS of existing flows. The mobility and the fluctuation of bandwidth make useless to estimate the impact of new incoming flows at existing ones. This why we use CAC only to check the ability of the network in providing required end-to-end delay before admission.

C. Dynamic Class Selection

At the source node, this mechanism determines the corresponding minimum class of each flow according to received information from CAC (D_{e2e} for class N). As our model provides proportional end-to-end between classes along the same path, the corresponding class is calculated as $p_i(t) = arg_{min_i} \frac{\delta_i}{\delta_N} \times D_{e2e}\ for\, i\ \in\ \{1, 2, \ldots, N\}$. DCS begins by tagging packets with the lowest corresponding priority, and compares received QoS report feedback with the required one. If QoS parameters are not satisfied, it increments the priority by one until the perceived QoS is satisfied, or it stays in the same class if it reaches the maximum priority level N. This mechanism works as follows:

$$\begin{cases} C_i^0 = p_i(t) & \\ C_i^{k(T+1)} = C_i^{kT} + 1 & if\ (C_i^{kT} < N \wedge QoS_{par} \notin SAT) \\ C_i^{k(T+1)} = C_i^{kT} & if\ (C_i^{kT} = N \wedge QoS_{par} \notin SAT) \\ C_i^{k(T+1)} = C_i^{kT} - 1 & if\ (C_i^{kT} > 1 \wedge QoS_{par} \in SAT) \\ C_i^{k(T+1)} = C_i^{kT} & if\ (C_i^{kT} = 1 \wedge QoS_{par} \in SAT) \end{cases}$$

Where i is a flow indicator and SAT is the satisfaction set of QoS parameters.

D. Bandwidth Estimator and Congestion Control

When a new flow arrives, the scheduler and the DCS at the sender of each flow try to accommodate with network load variation. However, these mechanisms are not efficient when there is not still enough network capacity. In such situation, all real time traffic will increase their classes. Therefore, the collision rate will increase and the throughput will decrease to zero. The only solution is the rejection of one or more flows in order to re-establish the QoS of the remaining flows in the network. Congestion detection is realized by the bandwidth estimator mechanism, which monitors the idle channel time. Periodically, bandwidth estimator notify the value of idle channel time to congestion control mechanism. When this value is less than pre-defined threshold, the CC component will select a victim flow from class k to be rejected, according to rejection parameters that are associated to classes in a proportional manner, e.g. $\kappa_i = \frac{threshold}{\delta_i}$, where $\kappa_1 > \kappa_2 > \cdots > \kappa_n$. The higher the priority, the smaller the rejection parameters. If congestion control mechanism at every node that detects congestion, selects one flow from the class with the higher rejection parameter and drop it immediately, there will be an under-utilization of the resources. Therefore, after flow selection, the congestion control wait for random time generated form $[\theta_1, \theta_2]$ where $\theta_1 = i \times \Delta$, $\theta_2 = (i+1) \times \Delta$, $\Delta = \theta_2 - \theta_1$ and i is the class priority. At the end of the triggered timer, the CC rechecks the channel utilization ratio, to verify if it still under the rejection ratio. In such case, the rejection starts by forwarding route error towards the destination, and stop forwarding any route request originated form that source for some time period in order to allow the rejected traffic to be rerouted far from congested area. when a flow is rerouted due to link breaks, the unused resources on the old route are distributed between existing classes. In contrast, if at the expiration of the timer the channel idle time is higher than rejection parameters of the flow, the flow will not be rejected because this indication means congestion has been alleviated due to rejection of other flows or the absence of interference. In this way, congestion control are completely distributed and does not require the exchange of control message between neighboring nodes.

E. Network Layer and Waiting Time Priority Scheduler

The classifier handles the received packets by forwarding them to the appropriate waiting queue, where they wait before transmission to MAC layer. The WTP scheduling is used to provide differentiation at the network layer in the same manner as in IP networks by selecting the packet with the longest normalized waiting time before forwarding it to the MAC layer.

IV. PERFORMANCE EVALUATION

In this section we study the performance of the proposed scheme using simulations performed in QNAP. Queueing model is used due to its flexibility in adding time to the header of each packet and its offered facility in accessing HOL packets information from other queues.

We have chosen a a small grid topology as shown in figure 4), of (3×3) with a size of $750m \times 750m$ and a transmission range of $400m$ for each host, and with linear mobility in the four directions for all nodes, except A and C supposed fixe. The destination and the sources are randomly generated in addition to static delay sensitive flow from A to C of $20\mu s$. When node B fails for an exponential delay used to simulate mobility and link break when node moves out, existing traffic from A to C will travel through AE along the path AEC to reach required destination. We use the on-demand Dynamic Source Routing (DSR) to determine the routes.

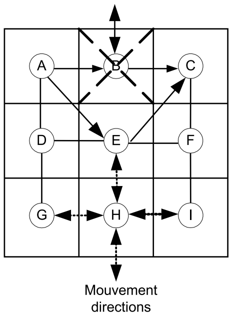


Fig. 4. Topology used in simulation.

We briefly describe the experimental setup and system configuration of our proposed model. Next, we present the results demonstrating the effectiveness of the proposed model in providing proportionality.

The robustness of our proposed EPDS scheme is tested using two different packet arrival profiles: Poisson and Pareto $inter-arrival$ distributions. Poisson is the most widely popular traffic model because it takes into account the fluctuation of traffic. The time t between arrivals is exponentially distributed with rate λ:

$$Pr(t \leq T) = 1 - e^{-\lambda t}$$

and the number of arrivals in an interval of length t is then given by the Poisson probability:

$$Pr(n\, arrivals \in [0,t]) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

In contrast, recent studies and measurements show that realistic traffic follows heavy tailed distribution where the variance of data size is very large, even sometimes not finite and that can not be represented by Poisson distribution. Heavy tailed distributions are more convenient, e.g. Pareto distribution function given in equation 4 is an example of heavy tailed distribution. However, a robust model should not depend at distribution load assumptions for providing QoS.

$$Pr(t \leq T) = 1 - \frac{1}{t^{\kappa}} \tag{4}$$

Therefore, we consider Pareto traffic arrivals for each class, where the packet arrival process follows the Pareto distribution with a shape parameter equals to $\kappa = 1.2$. All packets are constant length with 512 bytes.

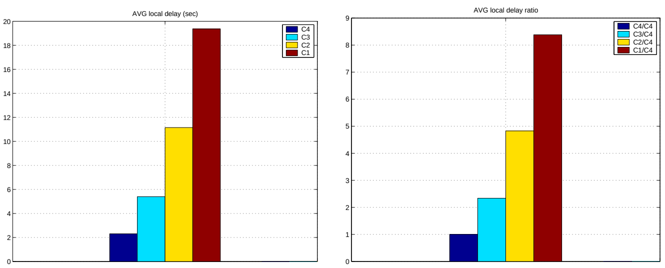
We first study the accuracy of EPDS model in providing differentiation between classes according to the pre-specified ratios at the same node and under the two arrivals pattern. We focus on scenarios of only four service classes at the network layer mapped directly to the 4 access categories used in IEEE 802.11e at the MAC layer. All the parameters investigated in the simulation of our model are given in table I. Results concerning the local average delay at a node are presented in figure 5, 6. It is obvious from these figures that average delay differentiation is mostly achieved simultaneously between different service classes according to their differentiation weight.

Parameters	*Value*
Number of classes at the network layer	4
Number of classes at the MAC layer	4
Differentiation parameters δ_i, $i \in \{1,2,3,4\}$	$\delta_1 = 1$, $\delta_2 = \frac{1}{2}$, $\delta_3 = \frac{1}{4}$, $\delta_4 = \frac{1}{8}$
MAC $CW_{i,min}$, $i \in \{1,2,3,4\}$ for EDCF	[64, 32,16, 8]
MAC $CW_{i,max}$, $i \in \{1,2,3,4\}$ for EDCF	1024
MacOverhead	28 Bytes
$aSlotTime$	$9\mu s$
$SIFS$	$16\mu s$
$DIFS = SIFS + 2 \times aSlotTime$	$34\mu s$
$AIFS_4$	$DIFS$
$AIFS_i = AIFS_{i+1} + aSlotTime$. $AIFS[4]$, $AIFS[3]$, $AIFS[2]$, $AIFS[1]$	$34\mu s$, $43\mu s$, $52\mu s$, $61\mu s$
Average weights α, δ, β	$\alpha = 0.9$, $\delta = 0.1$, $\beta = 0.1$
Per-class queue size (packets)	512bytes
Propagation delay	$1\mu s$
Delay jitter tolerance ε	20% of application delay

TABLE I

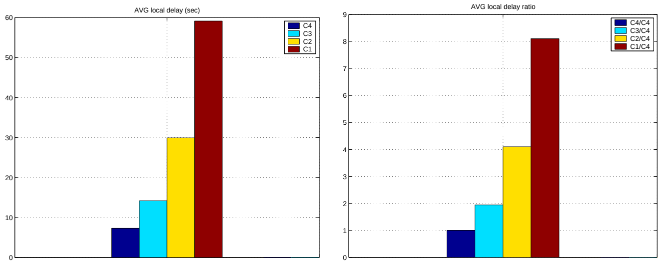
SIMULATION PARAMETERS.

User mobility leads to network topology changes after link breaking and thereby rerouting of all forwarded flows along the old path. When this occurs, traffic distribution changes significantly at other nodes in the same reception zone, and a transient perturbation of the proportionality ratio will occur and thus will result in short timescale violation of proportionality. This perturbation will not appear in the average and therefore a transient study is necessary to detect the influence of mobility at performance degradation. Figures 8, 7 show a non significant perturbation at a local node where proportionality between classes nearly continues to hold in the first 300 sec of simulation run. The end-to-end delays proportionality continue hold perfectly with respect to differentiated parameters of $1 : \frac{1}{2} : \frac{1}{4} : \frac{1}{8}$, where we observe that the end-to-end achieved waiting time ratios are significantly closer to the target ratios. Velocity of each mobile node was taken 1m/sec during simulation.



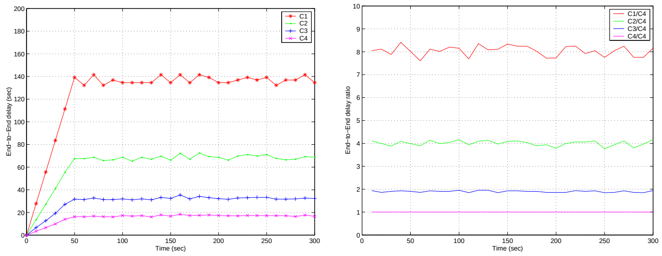
(a) Average local delay. (b) Average local delay ratio.

Fig. 5. Inter-arrival is exponentially distributed.



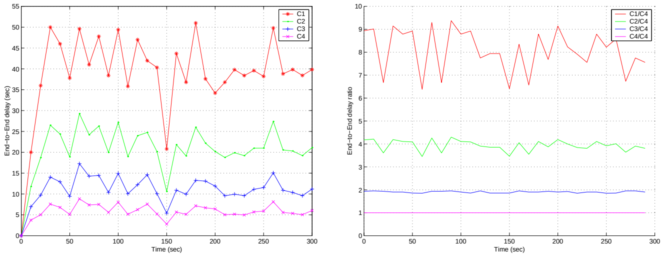
(a) Average local delay. (b) Average local delay ratio.

Fig. 6. Inter-arrival is Pareto distributed.



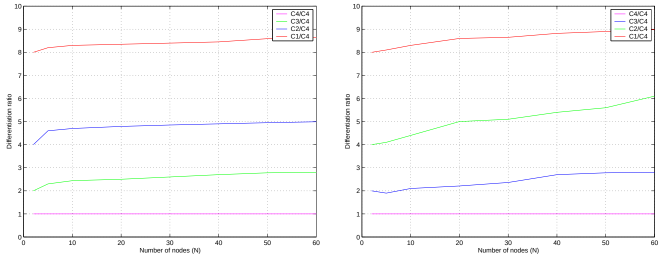
(a) End-to-End delay. (b) End-to-End delay ratio.

Fig. 7. End-to-End delay and delay ratio with Poisson distribution.



(a) End-to-End delay. (b) End-to-End delay ratio.

Fig. 8. End-to-End delay and delay ratio with Pareto distribution.



(a) Exponential inter-arrival. (b) Pareto inter-arrival.

Fig. 9. Impact of network size.

Then we extend the study to the impact of network size N at differentiation parameters. The variation curve is presented in figures 9(a) and 9(b) for Exponential and Pareto inter-arrival pattern respectively. We observe that the achieved differentiation ratios are nearly equivalent to their assigned differentiation weights when the network size is small $(N \leq$

10). In contrast, when the network size is large (e.g. $N \geq 40$), our scheme tries to maintains a differentiation index close to the target, but it suffers from the number of collision that grows exponentially with the number of nodes (N).

Furthermore, our model results in a significant performance gain over EDCF that initializes its parameters in a static manner, regardless of channel condition. The gain appears in terms of enhanced throughput, reduced access delay and reduced collision probability even under a large size networks.

V. CONCLUSION

In this paper, we have investigated the problem of delivering high priority packets without over-compromising low priority classes by controlling the quality spacing between different classes. We study the problem of providing proportional delay differentiation and we show the impact of tuning selected parameters of EDCF mechanism of IEEE 802.11e to provide and maintain service differentiation in the channel.

We investigate the impacts of different arrival pattern rules and show that our proposed scheme has the ability to softly re-adjust bandwidth among different classes, in contrast to current QoS differentiation mechanisms that depend at specific assumptions of the inter-arrival distribution of traffic pattern. Our scheme also makes the performance of network adaptively configurable by themselves which will minimize the impact of mobility at performance parameters.

From the performance point of view, we can also observe that our model scheme is an efficient way in providing differentiation between classes in predictable and controllable way. Moreover, our scheme is easy to implement and it works in a completely distributed fashion. Finally, our proposed model does not relay at any specific scheduler, and it is possible to incorporate any proportional scheduling mechanism other than Waiting Time Priority (WTP), to provide better support for differentiated services in mobile ad hoc networks.

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