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Management of Services Differentiation and Guarantee in IEEE 802.11e Wireless LANs

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***Abstract*— In this paper, we study the management and control of service differentiation and guarantee based on enhanced distributed function coordination (EDCF) in IEEE 802.11e wireless LANs. Backoff-based priority schemes are the major mechanism for Quality of Service (QoS) provisioning in EDCF. However, control and management of the backoff-based priority scheme are still challenging problems. We have analysed the impacts of backoff and Inter-frame Space (IFS) parameters of EDCF on saturation throughput and service differentiation. A centralised QoS management and control scheme is proposed. The configuration of backoff parameters and admission control are studied in the management scheme. The special role of access point (AP) and the impact of traffic load are also considered in the scheme. The backoff parameters are adaptively re-configured to increase the levels of bandwidth guarantee and fairness on sharing bandwidth. The proposed management scheme is evaluated by OPNET. Simulation results show the effectiveness of the analytical model based admission control scheme.**

Keywords- Quality of Service; 802.11 Wireless LAN; Admission control; CSMA/CA;

I. INTRODUCTION

With the commercial success and increasing deployment of IEEE 802.11 WLANs, it is expected that real-time services with stringent Quality of Service (QoS) requirements will be supported over such networks [1][2][3]. Although there are already many solutions for the wired networks and cellular networks, QoS support is still limited in the MAC layer of current 802.11 standards. Task Group *E* was created by IEEE 802.11 Working Group to work on the standardisation of 802.11e to enhance the QoS capabilities [4][5]. In the 802.11e MAC layer, a channel access function, Hybrid Coordination Function (HCF), is proposed. HCF includes both contention-based channel access and centrally-controlled channel access mechanisms. The polling-based scheduling scheme proposed in 802.11e provides contention-controlled channel access to guarantee stringent QoS for real-time applications. The contention-based channel access scheme is referred to as Enhanced Distributed Coordination Function (EDCF). EDCF provides more flexible QoS support. The enhanced QoS schemes proposed in 802.11e will improve significantly the abilities of supporting real-time services over 802.11 WLANs. However, the scheduling scheme cannot support well variable bit-rate applications. Coexisting with other access points will also pose challenges to scheduling-based QoS provisioning. Thus we will focus on the contention-based QoS provisioning scheme in this paper.

In the contention-based QoS provisioning scheme of 802.11e, the backoff parameters, i.e., minimum and maximum contention windows, *CWmin* and *CWmax*, and inter-frame space, *DIFS,* are used to differentiate services. The abilities in differentiating services have been demonstrated by simulations and analytical models [6][7][8][9][10]. However, the service differentiation scheme is not sufficient to provide a complete and consistent QoS guarantee for 802.11e. The schemes of system configuration, queuing management and admission control should work together with the service differentiation scheme. In the draft of 802.11e, some guidelines are proposed for admission control in contention-based QoS provisioning, which is based on the measured collisions and used channel time [4]. But the guidelines are not sufficiently clear and complete to implement an efficient admission control scheme. Xiao et al improve the admission control scheme and propose two enhanced schemes [11]. In the enhanced schemes, required throughput and delay and transmission budget for an Access Category (AC) are taken into account in the admission control procedures. In the admission control schemes above, the access point provides the information on the transmission budget, but the admission control decision is made by the non-AP stations requesting admission themselves. It is obvious that the performance of the above admission control schemes will be largely affected by the traffic and by the amount of requested bandwidth. The quality of existing traffic may be affected by the newly admitted traffic. The parameters used to assist admission control introduce more control complexity. In both [4] and [11], the configurations of parameters in the QoS Parameter Set Element (*QPSE*), including *CWmin*, *CWmax*, *AIFS* and *TXOPBudget* for each AC are not solved. Thus we believe that the admission control schemes are empirical and not efficient for QoS guarantee.

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In this paper, we will study a centralised admission control scheme. The research goal is to propose a simple QoS management scheme which can consistently and efficiently guarantee QoS for bandwidth subscribers. In the admission control schemes proposed in [4][11], the admission decision is made based on the transient measured parameters which will result in inconsistent QoS guarantees. To provide better QoS performance, we believe that the admission decision should be made by the access point, which has global and historical information of the network. The information will be important for consistent QoS guarantee. The *QPSE* parameters should also be calculated by the access point and used to assist in service differentiation and guarantee. In the next sections, we will present the proposed QoS management scheme and initial performance evaluation results.

II. FRAMEWORK OF A QOS MANAGEMENT SCHEME

In the proposed QoS scheme, backoff parameters are assumed to provide differentiated services. The proposed QoS management scheme is shown in Figure 1. There are five major modules in the QoS management scheme, which are *QPSE* configuration, throughput calculation, admission control, performance monitoring, and *QPSE* adjustment. We will describe those modules in the next subsections.

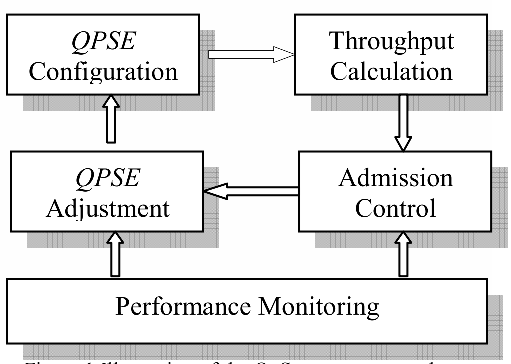

Figure 1 Illustration of the QoS management scheme

A. QPSE Configuration

QPSE configuration is used to set the backoff parameters for the stations in each AC[i], i=[1,…,4]. In the initial configuration, the expected traffic to be admitted for each AC, the pricing schemes and traffic patterns should be taken into account in the parameter configuration. As the predictions on the traffic, channel qualities and achievable throughput may be inaccurate, the configurations will also be subject to future adjustment. After the expected traffic is determined, the *QPSE* values can be configured by experience or using analytical models. For example, in the analytical models proposed in [9], it is observed that the achievable throughput of a station is proportional to the minimum contention window. Such observations can be used to guide on finding reasonable configurations.

B. Throughput Calculation

In this module, the saturation throughput of stations in the network will be calculated based on the configured *QPSE*. The throughput will be used further in the admission control module to make admission decision. It is clear that using saturation throughput as the achievable bandwidth for a station requesting QoS may reduce the number of stations that can be actually admitted into the network. But this approach is simple and can provide better QoS guarantees. And the unused network bandwidth for admitted traffic can be utilised by best effort traffic, thus the network bandwidth will not be wasted.

In the literature, there is already much work on the performance analysis of CSMA/CA mechanism used in the WLAN MAC layer. Backoff-based priority schemes for 802.11 also attract research interests [8][9][10][11]. The relationship of contention window and saturation throughput has been accurately modelled by the means of Markov Chains. However, the impact of inter-frame space DIFS (AIFS for 802.11e) is mainly studied by simulations. In [12] an analytical model for AIFS based service differentiation scheme is proposed. But the model is very complex. We have also proposed a simple tended Markov Chain model to understand the impact of DIFS on the differentiation of saturation throughput. The proposed analytical model has been validated by OPNET simulations. It is observed that the model is accurate in most of the studied scenarios and can be used for the purposes of admission control and QoS management scheme proposed in the paper. It should be noted that in most of the analytical models, saturated traffic is assumed and average throughputs for a single service class or single node are considered. The transmission rate and packet lengths of the stations are assumed fixed, while in the actual systems, those parameters may be changed from time to time. The locations of the nodes are also fixed. The differences should be taken into considerations in the practical use of the analytical model for admission control.

C. Admission Control

The basic idea of admission control in the proposed QoS management scheme is similar to those used in the wired network and other wireless networks. After receiving a QoS request (for uplink or downlink bandwidth) from a non-AP station, AP will calculate the achievable throughput for the station. As discussed above, saturation throughput calculated by the analytical models will be used to approximate the achievable throughput. The QoS request is admitted if the achievable throughput is larger than the request bandwidth and the QoS of other admitted traffic will not be violated; otherwise, the request is rejected. The admission control may be conservative, but it can provide better QoS guarantees.

Specific attention should be paid to the downlink bandwidth reservation. To provide bandwidth other than the reserved downlink bandwidth, the access point should have greater ability to access the channel. Without loss of generality, we assume N service classes in the network, each having n_i stations, $i=1,2,\ldots,N$. The concept of service class is similar to the AC defined in 802.11e. Let $SRu(i,j)$ and $SRd(i,j)$ denote the requested uplink and downlink bandwidth of the jth station in the ith class respectively. Let $SAu(i,j)$ and $SAd(i,j)$ denote the achievable bandwidth for the jth station in the ith class respectively. Let B denote the achievable throughput of the network in theory. Let $QPSE(i)$ denote the $QPSE$ for the ith service class. Let $QPSEa$ denote the $QPSE$ for the access point, *Sra* denote the overall requested downlink bandwidth. The achievable bandwidth *SAu(i,j)* and *SAd(i,j)* can be obtained based on the analytical model for saturation throughput or based on simulations. To provide guaranteed bandwidth, the following conditions should be satisfied.

$$\begin{cases} SRu(i,j) \le SAu(i,j), \\ SRa = \sum_{i,j} SR\_d(i,j) \le SAa, \\ \sum_{i,j} SRu(i,j) + SRa \le B, \quad j = 1,\dots,n_i, \quad i = 1,\dots,N \end{cases}$$

If the above conditions cannot be satisfied, the access point will consider adjusting the *QPSE* for all the AC and calculate the achievable throughput. If after several adjustments, say *Nt*, no *QPSE* can be found satisfying the conditions, then the QoS request will be rejected. If there is a set of *QPSE*, based on which the above conditions can be satisfied, then the QoS request will be conditionally accepted. If in the following *Nm* measurement periods, the requested bandwidth of some stations is not satisfied, then the conditional accepted stations will be rejected. By this means, the traffic from admitted stations can be better protected.

D. Performance Monitoring

In this module, access point will listen to the channel and record the channel activity. The information may include traffic density, successful transmissions, collided transmissions, data rate of each transmission, packet length and so on. The measured values of several parameters will be used for comparison with the analytical values and the requested bandwidth (or delay). Denote *SM(i,j)* the measured throughput of the *j*th station in the *i*th service class. Denote *SMa* the measured throughput of access point. Based on the comparison result, some conditionally accepted stations may be rejected.

$$\begin{cases} SRu(i,j) \le SM(i,j), \\ SRa = \sum_{i,j} SR\_d(i,j) \le SMa, \quad j = 1,\dots,n_i, \quad i = 1,\dots,N \end{cases}$$

The *QPSE* for each AC may be adjusted to adapt to the traffic fluctuations and provide fair share of the unsubscribed bandwidth.

The non-AP stations will also record the successful transmission and collided transmission. Then we can introduce a new variable, level of satisfaction (*LoS*), as the ratio of achieved bandwidth to the subscribed uplink bandwidth. Denote *S(i,j)* the *LoS* of the *j*th station in the *i*th service class. It is clear that *S(i,j)* can be expressed as,

$$S(i,j) = \frac{SM(i,j)}{SRu(i,j)}$$

LoS of the stations and the access point will be used for admission control. If *LoS* of some stations is lower than a defined threshold, *LoSth*, then the conditionally accepted stations will be rejected. The admitted stations with lowest *LoS* may be considered for a new admission control. If all the *LoS* of admitted stations are higher than *LoSth*, the measured *LoS* will be used by the access point to adjust *QPSE* for fair share of unsubscribed bandwidth. It will also be used as a metric for the performance evaluation of the proposed QoS management scheme.

E. QPSE Adjustment

To guarantee the requested bandwidth and fair share of unsubscribed network bandwidth, the access point will adjust QSPE for each AC based on the *LoS* of the stations in the AC. To ensure the system stability, the adjustment is made on just one AC for each adjustment period *Ta*. If a new station is admitted into the network, then the AC with highest *LoS* (achieved by averaging the *LoS* of stations in the AC) will be adjusted first to reduce its *LoS*. If there are some stations leave the network and set free reserved bandwidth, then the AC with lowest *LoS* will be adjusted to increase its *DoS*. After the adjustment, the access point will re-configure the non-AP stations.

III. PERFORMANCE EVALUATION

In this Section, some simulation results will be presented to evaluate the effectiveness of the proposed admission control scheme. The effectiveness of the control scheme will be mainly determined by the accuracy of the analytical model to predict the achievable throughput and/or delay performances, and the feasibility of making admission control decisions based on the predicted achievable performances based on the analytical models. As there are already studies on the analytical model and evaluation of the accuracy of the analytical models, we will not discuss the details here due to limited space. In the next, we will focus on the evaluation of the feasibility of admission control based on the analytical models. In most of the analytical models proposed and studied for the IEEE 802.11e, saturated traffic, generalized traffic pattern and communication channels are assumed. The throughput achievable for a single station is also long-term averaged. In order to use the analytical models for admission control, we need check the variations of the throughputs of a single stations, bandwidth guarantee for a station in short term, and the ability to guarantee the bandwidth for an admitted station when the traffics from this station or other admitted stations changes. The above issues are studied based on simulations in OPNET [13] and will be analysed in our future work.

As we discussed above, if a station is admitted into the wireless network, it will care about not only the long-term averaged throughput and/or delay, which can be obtained by analytical models, but also the instantaneous short-term throughput and/or delay. We will first present the study on how close the instantaneous throughput is to the averaged throughput.

The simulation scenario is shown in Figure 3. The channel bandwidth is set as 12 *Mbps*. Packet length is set 1000 *kbytes*. Service differentiations with both basic access mechanism and RTS/CTS based access mechanisms are evaluated. In the simulations, 5 different settings on the backoff parameters and DIFS parameters are configured in Table 1 for the purpose of service differentiation. In the later of the paper, we will use simulation sequence to denote the service differentiation configurations. The first 5 simulation sequences are associated with the basic access mechanism and the backoff parameter configurations in Table 1, while the later 5 simulations sequences are associated with RTS/CTS access mechanisms.

Table 1. Simulation parameters for service differentiation

	CWMin1	*CWMax1*	*DIFS1*	*CWmin1*	*CWMax1*	*DIFS1*
S1	31	511	2	31	511	4
S2	31	511	2	31	511	6
S3	15	255	2	31	511	2
S4	15	255	2	63	1023	2
S5	15	255	2	31	511	4

To get more insights into the service differentiation and guarantee, an ad hoc communication approach is used, which means each node can hear and transmit to any other nodes in the wireless LAN. MAC buffer size is 256000 bits. In the first set of simulations, we study the variations of the saturated throughput. The traffic of each node is generated fast enough. Each node will have packets to transmit whenever it can transmit. For simplicity, we only consider the case of two service classes. Access point is not presented in the simulated networks. The number of class one nodes is set to 5. The number of class two changes in [5, 10, 15 20]. The results are presented with the number of class two nodes 10 and 20.

Under the saturated network scenarios, we collect and analyze the statistical performances of per node and the network. Figure 2 presents some typical results on the instantaneous single node throughput and its cumulative distribution function (CDF) for class one and class two nodes. It can be observed that the CDF curves are steep, which is helpful for designing admission control schemes based on the calculated analytical throughputs. For example, in most of the studied simulation scenarios, the

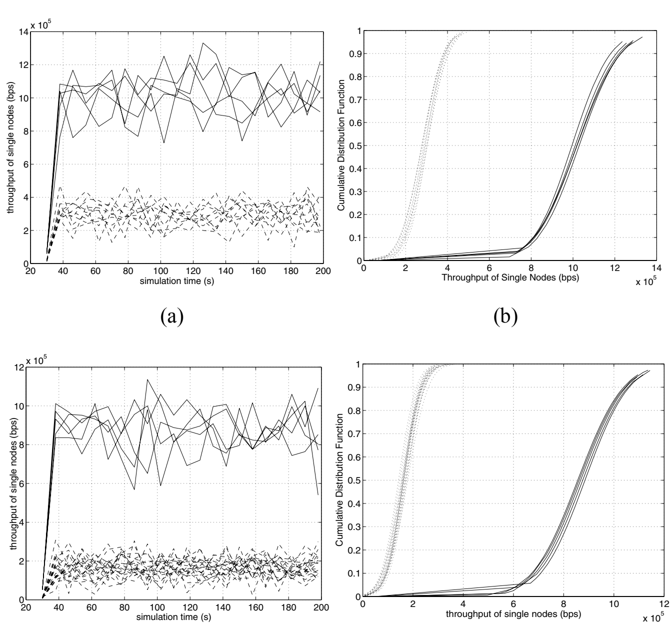

Figure 2 Throughput and CDF for class one and class two nodes. 5 class one nodes, solid lines for class one nodes and dashed lines for class two nodes. (a) Throughput, 10 class two nodes; (b) CDF, 10 class two nodes; (c) Throughput, 20 class two nodes; (d) CDF, 20 class two nodes.

Figure 3 presents the mean and variation of per node throughputs for both service classes. The X-axis is the previously defined simulations sequences. For each simulation sequences, the average single node throughputs for the nodes of both service classes are processed. We calculate the mean and standard deviation of the average per node throughput in each service classes. Presented are the results for the network scenarios in which there are 10 and 20 class two nodes in the network. From the results it can be observed that the variations of the throughput for the different nodes in the same service class are not high. The ratio of standard deviation to the mean of per node throughput is normally less than 10%. It is desirable for service guarantee and admission control. The higher class nodes can achieve more stable throughputs. It is also observed that when the network is not too large, basic access mechanism can achieve comparable throughput of RTS/CTS access mechanism.

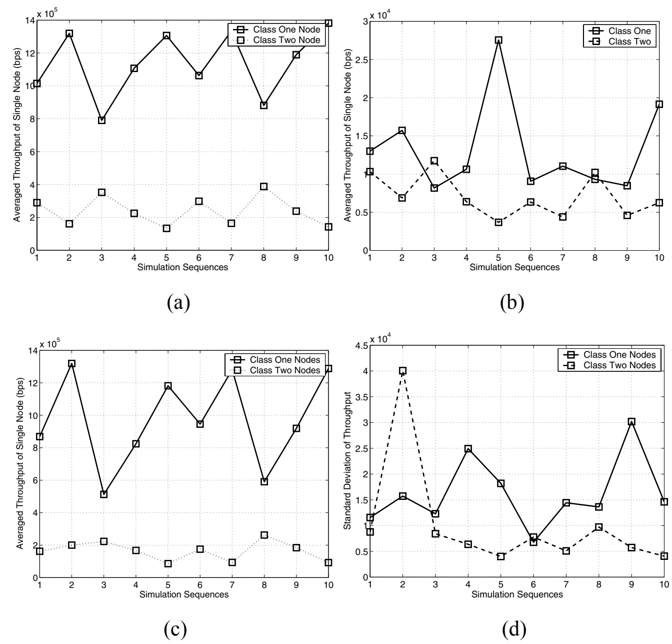

Figure 3 Mean and variation of per node throughputs versus simulation sequences. 5 class-one nodes. (a). Mean, 10 class-two nodes; (b) Standard deviation, 10 class-two nodes; (c) Mean, 20 class-two nodes; (d) Standard deviation, 20 class-two nodes.

To study the impact of unsaturated traffic on the service guarantee, we change the traffic patterns to observe the behaviour of the node throughputs. We have studied several types of traffic patterns. Only some general results will be presented to illustrate this issue. In the simulations, the traffic of the first 2 class-one nodes are generated with a constant interval of 0.03 second, and the traffic of the first 5 class two nodes are generated with a constant interval of 0.1 second, which are unsaturated in the considered network scenarios. Other nodes in the networks are provided with saturated traffic. It is observed from Figure 4 and Figure 5 that the bandwidth admitted class one and class two nodes based on the saturation analytical model can be guaranteed, which means the unsaturated nodes can achieve their subscribed bandwidth, and the saturated nodes will achieve bandwidth more than the saturated throughputs.

The unused bandwidth by the unsaturated nodes will be shared by the saturated nodes.

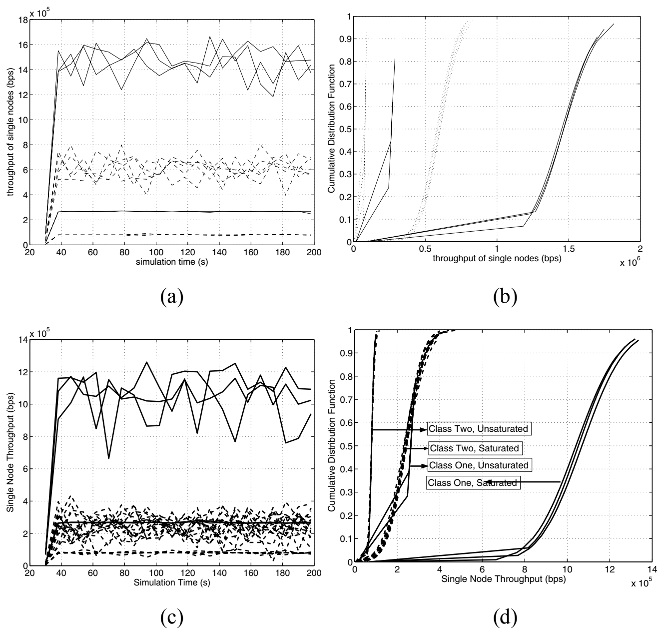

Figure 4 Throughput and CDF for class one and class two nodes with unsaturated traffic. 5 class one nodes, solid lines for class one nodes and dashed lines for class two nodes. (a) Throughput, 10 class two nodes; (b) CDF, 10 class two nodes; (c) Throughput, 20 class two nodes; (d) CDF, 20 class two nodes.

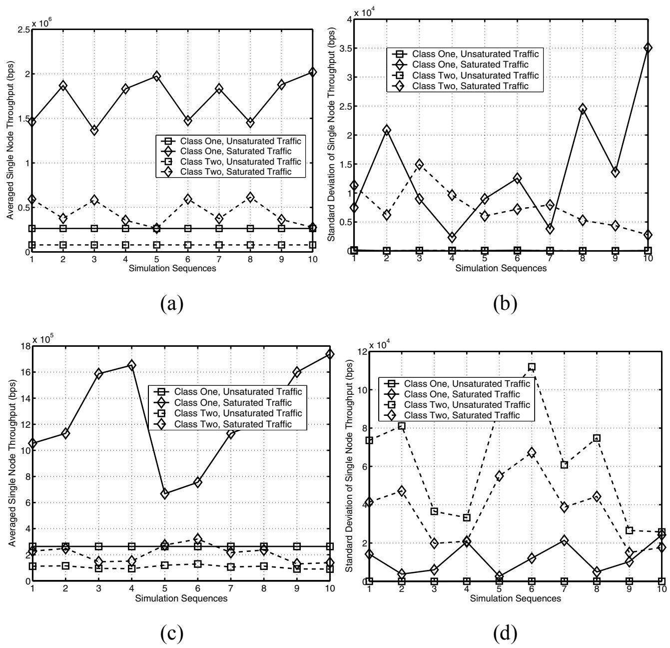

Figure 5 Mean and variation of per node throughputs versus simulation sequences with unsaturated traffic. 5 class-one nodes. (a). Mean, 10 class-two nodes; (b) Standard deviation, 10 class-two nodes; (c) Mean, 20 class-two nodes; (d) Standard deviation, 20 class-two nodes.

IV. CONCLUSIONS

In this paper, we studied the problem of contention based service differentiation admission control for wireless LAN. We proposed an analytical model based admission control scheme. The basic issues of such analytical model based admission control scheme are the accuracy of the analytical model to predict the achievable throughput and/or delay, and the feasibility of designing admission control polices based on the long-term averaged throughput. Simulations are carried out to evaluate the effectiveness of the admission control scheme. It is observed from the simulations that the analytical results can match closely to the simulation results. In the saturated networks, the variations of per node throughput are relatively small. This will be helpful for designing admission polices. It is also observed that the performance of service differentiation and guarantee based on the saturated throughput will not degrade by the changes on the network traffic pattern, which means the traffic from the traffic of the admitted nodes are not saturated. Thus the analytical model based admission control scheme is feasible. It has the merits of simplicity, accuracy and efficiency. The proposed QoS management scheme can be used to provide consistent QoS differentiation and guarantees. In the future, we will implement and evaluate a more complex admission scheme which has been proposed in the paper.

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