USER CLASS BASED QoS DIFFERENTIATION IN 802.11e WLAN

Amit Kejriwal, Ratan Guha
School of Computer Science
University of Central Florida
Orlando, FL-32816 USA
E-mail: {kejriwal, guha}@cs.ucf.edu

Mainak Chatterjee
Dept. of Electrical and Computer Engineering
University of Central Florida
Orlando, FL-32816 USA
mainak@cpe.ucf.edu

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ABSTRACT

802.11e is the new extension to the family of 802.11 standards which tries to provide QoS support to data services over the wireless LAN. However, it does not provide any mechanism to differentiate users which becomes a bottleneck for providing differentiated services to users from all sections of the society. In this paper, we study the 802.11e MAC protocol and suggest some enhancements to the current standard that will be able to provide QoS depending on the class a user belongs to in addition to the traffic category used by the user/station. Our algorithm takes into consideration the class of a user and the traffic category before any resource assignment is made. The algorithm has the scope for various tradeoffs that can be provided depending on the importance of the objective function: bandwidth utilization or prioritization of station's ability to transmit. Simulations were conducted to validate our algorithms and test their efficiency.

INTRODUCTION

The need for computing on the move has generated a need for wireless LAN market, with WLANs becoming more and more omni-resent. The mostly commercialized WLAN products available today are based on the IEEE 802.11 standard which has become the most prevailing technology for indoor broadband access for mobile devices. Alongside, the widespread use of networking multimedia applications has brought more requirements to the network and the service providers creating the need for end-to-end quality of service (QoS). The IEEE 802.11 working group is defining a new supplement to the 802.11 MAC called 802.11e which aims at providing toll-quality voice and video services over WLANs [2]. However, 802.11e does not have the option to allow the service providers to differentiate users based on their priority or subscription plans, and hence all users are still treated equally.

Classifying users into different classes and trying to retain them are becoming important strategies for the service providers. Most service providers have started offering differentiated services to users through their pricing plan for voice communication. The users are segmented and offered different values for their services. As the providers start introducing their wireless data services, most likely they will offer similar plans for the data services. In this context, the design of resource control should be based on the mutual benefits of the carriers and users. However, the big question is: what is the quality of wireless data services due to the new impediments created in the wireless networks? Traditionally, today's wireless voice network does not differentiate the QoS among the customers and their voice applications. In other words, the way the wireless network resources are shared between the different voice customers today, does not reflect any bias to the customer's preference or customer's subscription status. The problem lies in the fact that similar design philosophies cannot be used or extended for wireless data networks.

In our opinion, the concept of differentiated quality of service among customers of various classes will be an important parameter in the wireless data networks and services. The objective here is to create different classes of customers based on the selected service packages and provide distinction between the QoS levels like delay or throughput among these classes. In other words, the network must support different customers with different contracts with varying QoS or *service level agreement* (SLA). This motivated the work in this paper.

The rest of the paper is organized as follows. In section 2, we discuss the concept of traffic categories used in 802.11e along with the different timers used for channel access. In section 3, we introduce the concept of user classes and discuss possible scenarios that might arise. Section 4 presents the algorithms to tackle the different scenarios. The simulation is presented in section 5 and conclusions are drawn in the last section.

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EDCF: ENHANCED DISTRIBUTIVE COORDINATION FUNCTION

The distributed coordinated function (DCF) is the basis for the 802.11 protocol. An enhanced DCF called EDCF [3] has been proposed for 802.11e which provides QoS based on *traffic categories* (TC) [3]. 802.11e also introduces a concept of QoS-supporting basic service set (QBSS) [3]. QBSS is a BSS that includes the stations that are 802.11e complaint and can support QoS based services. These stations operating in the 802.11e mode are known as enhanced stations.

802.11e allows up to eight traffic categories which are used to differentiate among different traffic and hence priority can be assigned [3]. The traffic category with higher priority will have more probability to access the medium than the traffic category with lower priority [3]. This feature to support traffic priority was missing in the legacy 802.11. Also the DCF inter frame spacing, called DIFS, has been replaced by Arbitration inter frame space (AIFS) in 802.11e [3]. AIFS is different for each traffic category, and depends on the priority of traffic category. The traffic category with the highest priority has the lowest AIFS period and as the priority decreases the AIFS period increases as shown in Figure 1. AIFS value is at least equal to DIFS (i.e., $AIFS \geq DIFS = 34\ \mu s$) period for 802.11e to be backward compatible with the legacy 802.11 [2]-[3]. Each traffic category has its own backoff instance which also depends on the priority of the traffic category. EDCF stations waits for a period of AIFS when the medium is idle before starting their backoff function. The contention window (CW) never exceeds the parameter CW_{max} [TC], which is the maximum possible value for CW [2]-[3]. The minimum value depends on the traffic category and can take values between 0 and 255, thus $CW_{min}[TC]=0\text{-}255$ [2]-[3].

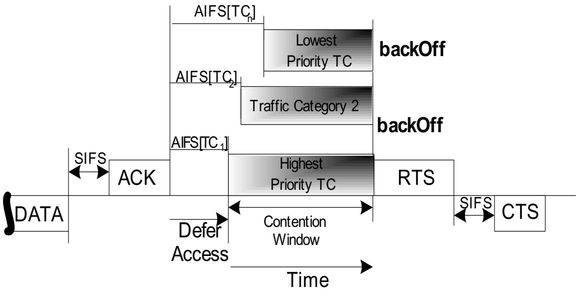

Figure 1: AIFS Classification for Different TC

A station always waits for its AIFS period before it starts transmitting. However, it does not mean that a station can always transmit when the backoff counter reaches zero because the medium can become busy. In that case, the backoff counter is frozen till the next time medium is free. The station resumes decrementing backoff counter again when the medium become free. If more than one traffic category's backoff counter becomes 0 at the same time, it results in a *virtual collision* [3]. Virtual collisions are avoided by letting the traffic category with the highest priority to transmit. One of the biggest differences between legacy DCF and 802.11e is that in legacy 802.11 the backoff counter is decremented by 1 after the first time slot of DIFS period, while in 802.11e the backoff counter is decremented by 1 from the last time slot of AIFS period [3]. This makes a big difference in the time when a node chooses a backoff instance. Legacy 802.11 increases the range of backoff value by twice after each unsuccessful transmission but in 802.11e the new backoff value is calculated using a parameter called PF (Persistence Factor) which takes different values (1 through 16) for different TC. Thus [3],

$$\text{newCW}[\text{TC}] = ((\text{oldCW}[\text{TC}] + 1) \times \text{PF}) - 1.$$

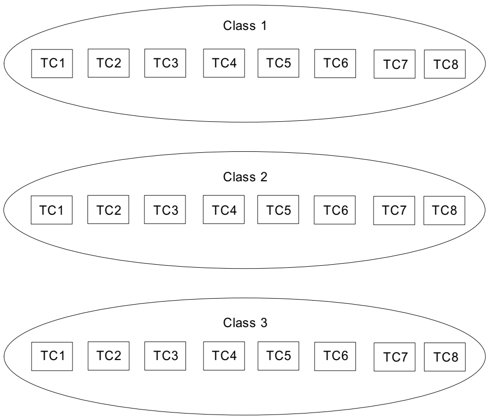

Figure 2: User Class and Traffic Categories

CLASS BASED QoS

802.11e does provide QoS by introducing traffic categories. Since all the traffic categories can potentially be used by every users/stations, there is no scope to differentiate among users. Let us assume that there are multiple classes of users all using the eight traffic categories. Figure 2 shows only 3 classes, namely Class 1, Class 2 and Class 3. We propose that the user classes be taking into consideration while deciding the time for a station to transmit. Normally, the total time that each station has to wait before trying to transmit is AIFS plus the contention window. We suggest that both the AIFS and the CW be made dependent on the class of the user and traffic category. Thus, for a station i to transmit, the time to transmit (TT_i) is given by

$$TT_i = AIFS\,[Class_i]\,[TC_i] + CW\,[Class_i]\,[TC_i].$$

Possible Scenarios

Before we propose our algorithms, let us introduce the possible scenarios that might arise due to the introduction of these multiple classes. The algorithm used to calculate the time for a station to attempt a transmission, must allow different variations in the priority based on class and the data traffic category used by the station. We consider that Class 1 has the highest priority and Class N has the lowest. In other words, the priority schedule is as follows:

Class 1 > Class 2 > Class 3 > ..…> Class N

Scenario 1: This is a trivial scenario where though there are multiple classes; there is no priority differentiation amongst the classes. The priority of a station to transmit is only differentiated by using the traffic category, which is essentially the same as supported by the current 802.11e. Figure 3 shows how the different classes are treated at par.

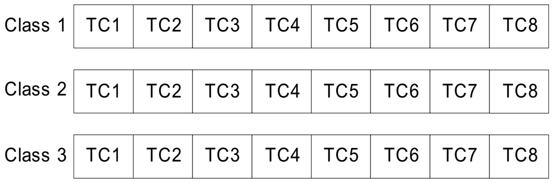

Figure 3: SCENARIO 1

Scenario 2: In this scenario, a higher class has the priority to transmit irrespective of the traffic category as shown in Figure 4.

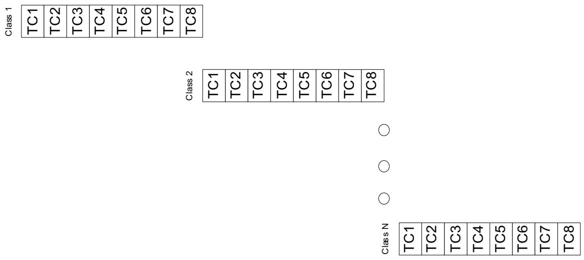

Figure 4: SCENARIO 2

Scenario 3 (General Scenario): In this scenario, only the corresponding traffic category with higher class has a priority over corresponding traffic category in lower class. However, there is a possibility that the priority difference to vary. For example the priority of TC_1 and TC_2 in class 1 may have priority over the TC_1 and TC_2 of class 2 or priority of TC_1, TC_2 and TC_3 in class 1 has priority over the TC_1, TC_2 and TC_3 of class 2 and this relationship continue throughout all the classes and traffic categories. Figure 5 shows this difference as Δj. Δj represents the number of traffic categories for a class that have priority over corresponding traffic categories in lower priority class.

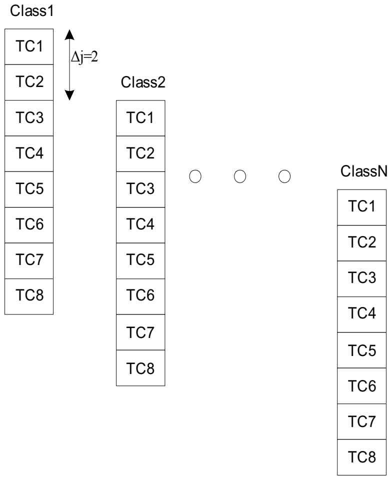

Figure 5: SCENARIO 3, WHEN Δj =2

PROPOSED ALGORITHMS

We first deal with the first two scenarios before we discuss the general scenario. The generalized algorithm for scenario 3 will encompass all the other scenarios just by changing the value of Δj.

Algorithm for Scenario 1

This scenario is similar to the one supported by the present 802.11e. In this scenario all users have same priority (only one class exists) but the difference in priority is among the traffic categories [3]. This case can be supported by allowing different AIFS and CW for different TC's priority. If TC_1 has highest priority then it can be scheduled as:

$$\mathrm{AIFS}[\mathrm{TC}_i] < \mathrm{AIFS}[\mathrm{TC}_j] \text{ if } i < j$$

As the CW_{max} is constant for a particular TC, therefore the mean value for the CW will be less for a traffic category with higher priority [3]. Therefore, time to transmit will be

$$\mathrm{TT}_i = \mathrm{AIFS}[\mathrm{TC}_i] + \mathrm{CW}[\mathrm{TC}_i]$$

Thus from the relationship between $\mathrm{AIFS}[\mathrm{TC}_i]$ and $\mathrm{CW}[\mathrm{TC}_i]$ we can say that

$$\mathrm{TT}[\mathrm{TC}_i] < \mathrm{TT}[\mathrm{TC}_j] \text{ if } i < j.$$

Algorithm for Scenario 2

In this scenario all traffic categories of a particular class will have more priority over traffic categories of all other classes of lower priority than that class. To achieve this relationship, first it is important to find out the time each station has to wait to transmit data depending on its class and traffic category.

$$TT_i = AIFS_i\,[Class] + CW_i[TC]$$

In this scenario, AIFS of the station is dependent on the class and CW is dependent on traffic category, thus time to transmit is dependent on both class and traffic category. CW [TC] can be found as it is suggested in 802.11e. To achieve the priority as described above, the relationship between i^{th} and $i+1^{th}$ class is:

$$AIFS_{i+1} - AIFS_i > CW[TC_n]$$

$CW[TC_n]$ is the maximum value of contention window produced by all the traffic categories. Thus, *all* traffic categories of a higher priority class will have more priority than all the traffic categories of a lower priority class.

Let *P* and *Q* represent the class of a user and the traffic category of the station respectively. Highest priority implies P=0 and highest traffic category implies Q=0. As priority decreases for both class and traffic category the value of P and Q increases by 1. Let us denote the time to transmit for a user belonging to class P and with traffic category Q by *TT [P] [Q]*. This scenario will maintain the following relationships:

$$TT[P][Q] < TT[P][Q+1]$$

$$TT[P][Q] < TT[P+1][Q]$$

The value for *Q* is *n* for TT[P][Q] and 0 for TT[P+1][Q]. In spite of these priorities, there is no way to eliminate the possibility of collisions, as this algorithm is basically collision avoidance and not collision elimination. So the algorithm should also include the penalty for unsuccessful transmission. When the number of unsuccessful transmissions reaches certain threshold, time to transmit by a station shall be increased as a penalty. Since this is a class based service, even after unsuccessful transmission, it may be preferable to have fewer penalties for a station with higher priority. The downside of having lower penalties for station with higher priority is that it might delay the transmission of data or starve the lower priority stations. So to avoid the delay, we do not penalize a station with higher priority until a certain number of retransmissions, say $\alpha_{Threshold}$. Thus, if the number of retransmissions is below $\alpha_{Threshold}$ the value of time to transmit remains unaffected. If the number of retransmission is higher than $\alpha_{Threshold}$ the time to transmit is increased by an *Increment Factor* (IF). Increment factor depends on whether the algorithm needs to be fair to all users or it needs to be favorable to the stations with higher priority, and is always greater than 1. Therefore the algorithm can be defined as follows.

```
if ( no.of retransmission < $\alpha_{Threshold}$ )
        $TT_i = AIFS_{class} + CW_{Trafficcategory}$
else
        $TT_i = IF \times (AIFS_{class} + CW_{Trafficcategory})$
```

Algorithm for Scenario 3 (General Scenario)

With the special scenarios discussed, we are in position to discuss the algorithm which will handle any scenario. Both classes and traffic category are interdependent, while deciding time to transmit. As use the same definition for P and Q. The time to transmit for user from class P having traffic category Q is represented by *TT[P][Q]*. The general relationships can be described as:

$$TT[P][Q] < TT[P][Q+1]$$

$$TT[P][Q] < TT[P+1][Q]$$

$$TT[P][Q] < TT[P-1][Q+1]$$

Recall, Δj represents the number of traffic categories for a class that have priority over corresponding traffic categories in the next lower class. In general, Δj can take values from 1 through *n*, where *n* is the number of traffic categories. For example, when Δj=2, the 2 consecutive traffic categories have priority over the same traffic categories in the next lower class. While the same two traffic categories of that lower priority class have higher priority over same traffic categories for the classes that have lower priority than itself. In general form of equation in the form of Δj the relationship can be expressed as:

$$TT[P][Q+\Delta j-1] < TT[P+1][Q]$$

$$TT[P][Q] < TT[P-1][Q+\Delta j]$$

$$TT[P][Q+\Delta j-1] < TT[P-1][Q+\Delta j]$$

The above inequalities explain the Δj relationship with the classes and traffic category. Let us now calculate the contention window. If Q is the priority value of traffic category, *r* is the priority value of class, and Dj = Δj. Initially the value of D is equal to D_j, D is reset to D_j once it reaches 0, p keeps track of TC, i represent the class category for which the algorithm is calculating CW_{max} and j represents the traffic category for which function is calculating CW_{max}.

```
$sum \leftarrow i + (r+1) \times ((j-1)/Dj) + ((j-1)\% Dj)$
        if $(D = 0)$ {
                $p \leftarrow p + 1$
                $D \leftarrow Dj$
        }
        $D \leftarrow D - 1$
$CW'_{max} \leftarrow sum + r \times p \times Dj \times MF + i$
        if$(i != 1)$
        $CW'_{max} \leftarrow sum - i + i \times (Dj - 1)$
```

MF is the *Main Factor*, where MF >1, defined as the difference in CW'_{max} value among the traffic categories which are Δj apart within the same class. Greater value of MF will increase the CW'_{max} value. The value of MF is a tradeoff between the bandwidth utility and providing higher probability to transmit to those stations that have higher priority. The higher value of MF will make sure that station with higher priority may have more probability to access medium but its bandwidth utilization may be very bad if the higher priority stations are not transmitting often. This will happen because even though the medium is free the lower priority stations have to wait for longer time before they can try to transmit as their time to transmit will be large. Value of CW_{max} depends on class and traffic category and is related to CW'_{max} as

$$CW_{max} = RF \times CW'_{max}$$

where RF is reducing factor to reduce the value of CW_{max} as sometimes the function may produce high values depending on the trade-off. Thus,

$$TT[P][Q] = AIFS + CW_{max}[P][Q]$$

AIFS can be kept at minimum in this case and that is equal to DIFS=34 μs. Value of AIFS will remain same for all values of class and traffic category. The algorithm will produce different values of CW_{max} depending on class, traffic category and Δj. The value of CW_{max} produced by above function are as desired by the algorithm. Thus *TT[P][Q]* relation will be stored as desired by class, traffic category and Δj.

SIMULATION MODEL AND RESULTS

We simulated our proposed algorithm with varying parameters. We considered 5 classes of users, 8 traffic categories, MF=1, RF=1and Δj=2. From Figure 6 we see that the desired relationship is maintained by the function. Since Δj=2, the value of CW_{max} for class 1 traffic category 1 & class 1 traffic category 2 should be less than Class 2 traffic category 1 & class 2 traffic category. Also the value of CW_{max} for class 1 traffic category 3 should be greater than class 2 traffic category 1 & class 2 traffic category 2.

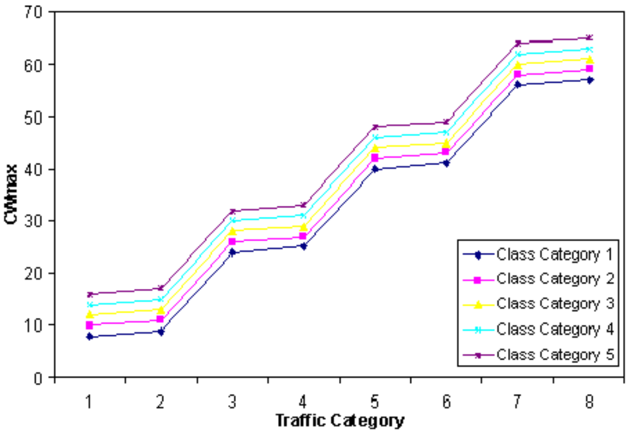

Figure 6: VALUES OF CWmax; Δj=2, MF=1

Also, in case of Δj=3 the required relationship is maintained as can be seen from Figure 7. Value of some class and traffic category is chosen to be near each other as to avoid bandwidth loss if there is no transmission from a high priority station.

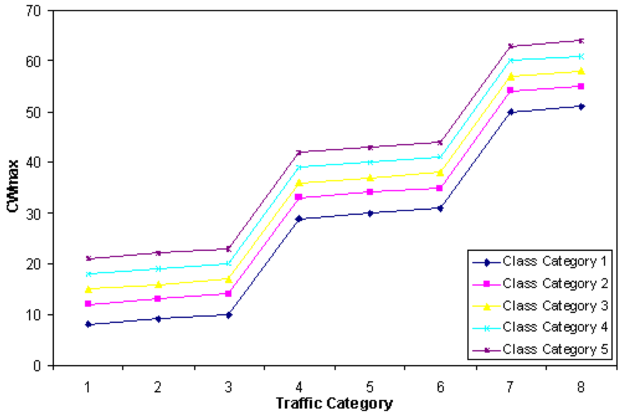

Figure 7: VALUES OF CWmax; Δj=3, MF=1

The effect of a different value of MF can be seen in Figure 8, where MF was set to 2. The values of class 1 traffic category 3 & class 1 traffic category 4 were 24 and 25 respectively in case of MF=1. But for MF=2 these values were 34 and 35 respectively. This shows that increase in MF will increase the value of CW_{max} value for every class and traffic category across the system. Using above shown algorithm the relationship as desired in Scenario 2 can be achieved by putting Δj=8.

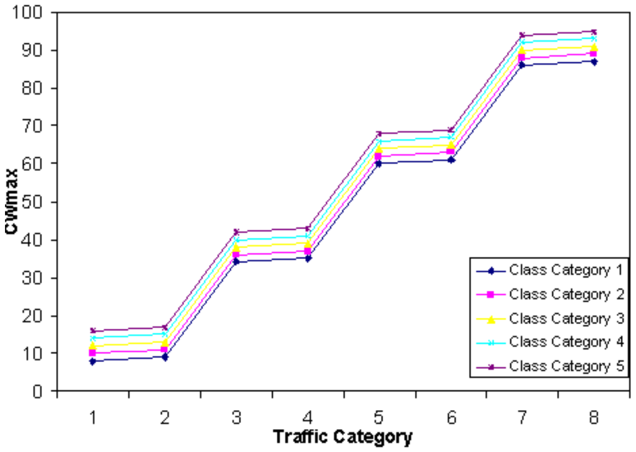

Figure 8: VALUES OF CWmax; Δj=2, MF=2

Mean of CW_{max}

The value of CW_{max} maintains the relationship as desired. Since CW_{max} gives the maximum value, a station can choose between 0 and CW_{max}. The mean for uniform distribution will be $CW_{max}/2$ for all the different value of CW_{max} depending on class and traffic category. In some cases there is a possibility that the mean may be too close for some values, in that case the probability of collision might increase. To reduce this collision probability instead of choosing random values between 0 and CW_{max}, a new function can be defined as a function of the user class, which will choose a random value between X and CW_{max}. X will be dependent on the class of the station. In that case the mean for uniform distribution will be $(X+CW_{max})/2$. X can be formally defined as

$$X = (P - 1) \times \Delta j$$

This way the mean value of CW can be changed.

Starvation

Algorithm for calculating CW_{max} may initially give an impression that it might produce starvation for the stations that have lower class and traffic priority. But in reality this is not the case since the algorithm is distributive and once a station chooses a value for CW_{max}, it does not reset CW_{max} in any case except collision. A new value is chosen for CW_{max} in case of a collision irrespective of station's priority. At any given instance of time a station with a higher priority will be given lower value of CW_{max} than lower priority station but once the value is chosen for any station it is not reset even if a higher priority station tries to claim the medium at some later instance of time. The value TT_i of lower priority station decreases every time it found the medium to be idle for more than AIFS period and thus once its back off counter reaches 0 it will be allowed to transmit irrespective of whether a station with higher priority is waiting to transmit and this simple but distributive approach will save stations with lower priorities from starvation.

Retransmissions

802.11e suggests that after an unsuccessful transmission, a new contention window using persistence factor (PF) be calculated. It is suggested that the value of CW be increased as follows:

$$newCW[TC] \geq ((oldCW[TC] + 1) * PF) - 1$$

In the solution presented for the class based QoS instead of increasing the value of the contention window after each unsuccessful transmission, we suggest that the value of CW is increased only after a certain number ($\alpha_{Threshold}$)of retransmission is reached. This way a station will not be penalized after each unsuccessful retransmission but will be penalized only after it consistently results in unsuccessful retransmissions. Also the value of the Persistence Factor will depend both on the class and the traffic category. To make sure that a station which has many consecutive unsuccessful retransmissions failure is not penalized heavily, we propose another variable, α_{max}, which counts the number of times the value of CW has changed consecutively before making a successful transmission. Once that reaches a certain threshold value, $\alpha_{maxthreshold}$, the value of CW is not increased any more but kept at the last increased value which makes sure that no station suffers from starvation.

```
if (no.of retransmission < $\alpha_{Threshold}$)
        newCW=OldCW

if(no. of retransmission ≥ $\alpha_{Threshold}$)
        and if ($\alpha_{max}$<$\alpha_{maxthreshold}$)
        $newCW[TC] \geq ((oldCW[TC] + 1) \times PF) - 1$
else
        newCW=OldCW
```

The added benefit of using α_{max} and $\alpha_{maxthreshold}$ is that these values can also be user class and traffic category dependent and thus different values can be assigned to different stations depending on the class and data's traffic category. If the values of PF change depending only on the traffic category the slope of the graph for each class will almost remain same as shown in Figure 10.

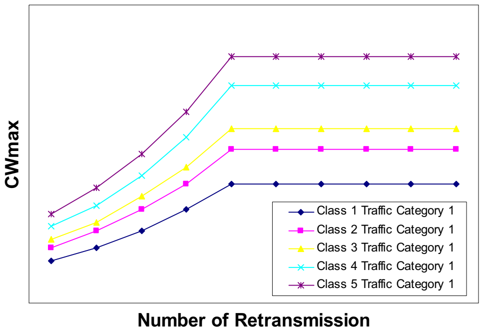

Figure 9: CW_{MAX}: PF IS DEPENDENT ON TC

If the value of PF is dependent on class and traffic category, the value of CW_{max} will have greater slope for lower priority class compared to the higher priority class as shown in Figure 10.

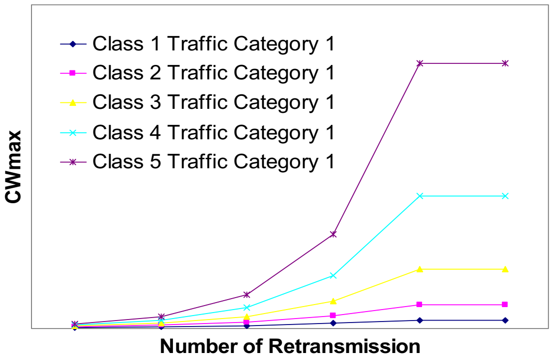

Figure 10: CW_{MAX}: PF IS DEPENDENT ON CLASS AND TC

CONCLUSIONS

In this paper, we proposed algorithms for class based QoS for 802.11e based WLAN services. Different aspects of algorithm can be tuned by controlling parameters like MF and RF to achieve the desired level of system performance. We considered different scenarios including the generalized one. Algorithms are distributive, simple and give flexibility for trade-offs depending on the demand for bandwidth or increasing probability to transmit for higher priority class. The benefit of using above suggested algorithm is that it provides alternate and more flexible way of providing QoS. Simulation results demonstrate that our proposed algorithms do provide the differentiation among different user classes.

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AUTHOR BIOGRAPHIES

Amit Kejriwal is pursuing his PhD in computer science at University of Central Florida and is a Sr. Software Developer working on Integrated Criminal Justice System. His interests include ad-hoc networks, network security and wireless networks.

Ratan Guha is a Professor in the School of Computer Science at the University of Central Florida. His research interests include modeling and simulation, distributed computing and networking, and network security.

Mainak Chatterjee is an Assistant Professor in the Department of Electrical and Computer Engineering at the University of Central Florida. His research interests include resource management and quality-of-service provisioning in wireless and cellular networks, sensor networks, CDMA data networking media access control protocols, Internet traffic, and applied game theory.