Chapter 3

Enhanced Distributed Channel Access with Contention Adaption

3.1 Background and literature work

Wireless technologies have brought great convenience to human life. Every one could access to the Internet without the wired constraints. Most of the wireless technologies apply on portable gadgets, such as personal digital assistant (PDA) or laptops. These instruments have a common characteristic: they lack constant electricity supply, and the only energy source is the battery. In the circumstance, how to sustain the battery longer is a big problem. There are five different physical actions for a wireless networking interface: to transmit, receive, idle, sleep, and off. When transmitting a frame, it consumes largest power since it needs to do modulation and send the packet over the air. To receive a packet needs fewer power than to transmit one. The wireless interface is called in the idle mode if it neither transmits nor receives a packet. An idle station consumes least power among the former three modes. While entering the sleep mode, a station would turn off most of its circuitry. On the other hand, off mode means a station completely turns off all the circuitry. So for the last two modes, off state could save more energy than the sleep mode. However, the off and sleep modes usually operate in the centralized situation. We will not discuss about the two states since the work basically focuses on the distributed networking configuration. As what has been mentioned earlier, to transmit a data consumes the largest energy. So to avoid unnecessary retransmission would be the most efficient technique for saving the energy.

Among various standards, the most prevalent one is IEEE 802.11. The original version could only support bandwidth up to $2Mbps$. The successors, such as IEEE 802.11b, 802.11a, and 802.11g, could provide bandwidth up to $54Mbps$. The original 802.11 standard does not guarantee any QoS. In 802.11, all stations vie for the medium with equal chances. IEEE 802.11e [2] was established in order to enhance the QoS deficiency in the origianl standard. Although the IEEE 802.11e has not been standardized yet, it has drawn numerous research interests. The numerical results in [22] show that 802.11e could provide substantial discrimination among different *ACs*. [23] compares the throughput of IEEE 802.11 DCF and IEEE 802.11e EDCA. It concludes that *EDCA CFB* could produce better results in overall throughput because the *CFB* scheme could ease the contention level especially when traffic load is high. According to [24], data dropped rate will be significantly reduced if *CFB* is adopted. This is because *CFB* could mitigate contention level when the load is heavy, which also decreases the collision probability. [25] discusses the impacts of certain parameters, such as frame size and mobility, on the system throughput. Based on the simulation results, although the mobility of one station may affect the throughput in DCF,*EDCA CFB* would not degrade the performance of EDCA much. [26] and [27] present analytical models of EDCA. They target on the saturation throughput analysis. [28] introduces a new concept called *Virtual Group*. Traffic is divided into various *Virtual Groups*. A station is only allowed to contend with those in the same group. The author investigated the delay and throughput performance.

3.2 The proposed solution

Even though the IEEE 802.11e EDCA could successfully guarantee the statistical priorities among various ACs, it still confronts severe deterioration in performance while traffic load is heavy. Because $EDCA$ is contention-based, stations suffer from serious collisions in high traffic load. Nobody could proceed successful transmission instead of serious contention in the circumstance. Meanwhile, energy consumption, which is critical for portable devices, is dissipated due to frequent retransmissions. Furthermore, it may be hard to meet the rigorous delay requirement of real-time applications since the duration for a successful packet delivery is long. For example, the one-way delay bound of a voice packet is $150\ ms$ including the wired and wireless transmission, and the loss rate must be less than 5%. Usually the packet delay bound for the wireless end is limited as $20\ ms$ [29]. Based on our simulation study, $EDCA$ could not always meet the QoS requirements of multimedia applications. Most of the former research presented in the previous section focuses on the analysis of EDCA performance. Only few of them aim to enhance the 802.11e EDCA based on the perspective of contention alleviation. In addition, none of them considers the energy conservation along with QoS guarantee. However, to save the energy is an important issue since most of the wireless technologies are used in portable instruments, which lack constant power supply.

In this paper, we propose *Enhanced Distributed Channel Access with Contention Adaption (EDCA/CA)*, which is an enhancement of the IEEE 802.11e EDCA with Contention Adaption (CA). As mentioned above, although EDCA prioritizes traffic into different *ACs* by various parameters, it could still suffer from considerable contentions when the load is heavy. For future multimedia services, it is also expected that applications would consume the wireless bandwidth heavily, which even worsens the situation. Our aim is to devise a method to improve the QoS. Even when the load is heavy, the packet delay could be reduced. Furthermore, one goal is to decrease the energy consumption since the energy is the most precious resource for portable gadgets. The last objective is the proposed method must completely comply with the 802.11e draft.

The proposed scheme only introduces two additional parameters: δ and $Nacc$ to solve the problem. Each *Access Category* in 802.11e could have its own δ and $Nacc$ values. We use the *frame queuing time* as a measurement of the current traffic load. The *frame queuing time* here is defined as the time when the frame enters the queue until the frame is dequeued;

that is, it is delivered successfully. Higher traffic load normally will increase the collision probability, which in turn yields longer waiting time for a succesful packet delivery. In the proposed method, every packet queuing time has to be evaluated and monitored. Once the queuing time of a frame exceeds δ*[AC]*, the *Accumulation Phase* will begin. After entering the *Accumulation Phase*, the AC stops contention even if it has frames waiting in the queue. The phase terminates when the number of accumulated frames exceeds $Nacc$*[AC]*. The AC will then continue its contention for the channel again.

Taking *AC_VO* as an example. The queuing time of every *AC_VO* frame is calculated and monitored. If the queuing time is lower than δ*[AC_VO]*, the operation is exactly the same as EDCA. Once the queuing time exceeds δ*[AC_VO]*, the station enters the *Accumulation Phase*. During this phase, the station is not allowed to contend for the channel. The *Accumulation Phase* stops when the number of queuing frames exceeds $Nacc$*[AC_VO]*. After that, the station continues its contention to transmit *AC_VO* again.

The basic idea of the proposed EDCA/CA is to pause some of the contentions when the traffic load is heavy. The frame queuing time is highly associated with current traffic load. Therefore, it could properly reflect the traffic load. Once the observed frame queuing time surpasses δ*[AC]*, the contention adaption begins. It will suspend some contention attempts to alleviate the load. Contention alleviation reduces the probability of collision, which in turn yields shorter frame queuing time and also avoids unnecessary retransmissions. Besides, it reduces the energy consumption because unnecessary retransmissions are eliminated. The EDCA/CA also takes advantage of *EDCA CFB*. The total transmission time of $Nacc$ frames including the corresponding acknowledgement frames must be shorter than $TXOPlimit$ in EDCA/CA. Therefore, a station could send out all the buffered frames within one *CFB* after gaining the *EDCA TXOP*. Although transmissions of some ACs may be suspended in the proposed scheme, it promises to deliver the detained frames continuously without further contention in one *CFB*. Besides, fewer contentions will be needed in the proposed EDCA/CA scheme because more frames are gathered in one transmission burst. The utilization of bandwidth will be improved compared with the original EDCA scheme. Furthermore,

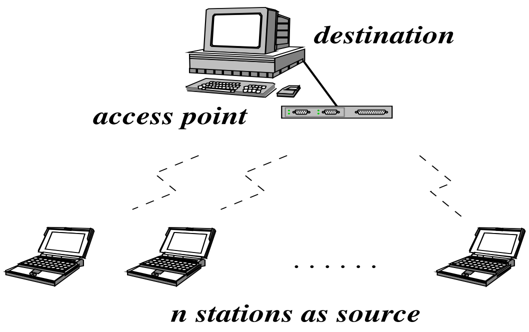

Figure 3.1: Simulation topology

the proposed EDCA/CA only introduces two simple parameteres without much modification of the IEEE 802.11e. In addition to evaluating every frame queuing time, no other complex process is needed. It is not only compatible with 802.11e but also easy to be realized.

3.3 Simulation and Numerical Results

We have conducted extensive experiments by using *Network Simulator version 2 (ns-2)* [30], which is a discrete-event driven simulator. The simulation topology is depicted in Fig. 3.1. There is only one destination node which connects to an AP by a 100 $Mbps$ link. The destination serves as a sink which receives the traffic generated from all of the wireless stations. The distance between the AP and each wireless station remains the same. IEEE 802.11b is adopted as the wireless medium. Table 3.1 shows the parameters used in the simulation. The parameters are mainly obtained from 802.11 and 802.11e documents. The power consumed on transmit, receive, and idle modes are 1.65 W, 1.4 W, and 1.15 W, respectively [31]. The value of δ is not a constant during the simulation process. The frame queuing time is monitored and the smallest K_δ delays are recorded every 1000 frame. δ is set as the mean of the smallest K_δ delays. By changing δ dynamically, it results in a better adjustment to the fluctuant environment.

Packet delay and energy consumption are investigated in our experiments. We em-

Table 3.1: System parameters

Parameter	Value	Parameter	Value
PHY	DSSS	bandwidth	11 Mbps
slot time	20 us	SIFS	10 us
TXOP[AC_VO]	3.264 ms	TXOP[AC_VI]	6.016 ms
TXOP[AC_BE]	0 ms	TXOP[AC_BK]	0 ms
CW_{min}[AC_VO]	7 slots	CW_{max}[AC_VO]	15 slots
CW_{min}[AC_VI]	15 slots	CW_{max}[AC_VI]	31 slots
CW_{min}[AC_BE]	31 slots	CW_{max}[AC_BE]	1023 slots
CW_{min}[AC_BK]	31 slots	CW_{max}[AC_BK]	1023 slots
AIFS[AC_VO]	50 us	AIFS[AC_VI]	50 us
AIFS[AC_BE]	70 us	AIFS[AC_BK]	150 us
$Nacc$[AC_VO]	2	$Nacc$[AC_VI]	2
K_δ[AC_VO]	100	K_δ[AC_VI]	100

Table 3.2: Traffic parameters

Type	Distribution	Rate	Packet size
Voice	Exponential	64 Kb	200 Bytes
Video	Constant Bit Rate	240 Kb	400 Bytes

phasize on voice and video traffic because they have more stringent requirements on QoS. Besides, our proposed solution requires the advantage of CFB, which could not be used for the other two ACs (AC_BE and AC_BK) since the *TXOPlimit* for the two is defined as 0 in the 802.11e draft. Each wireless station has two audio flows and one video flow in our simulation settings. Table 3.2 indicates the traffic parameters used in our experiments.

There are two sets of simulation experiments. The first set mainly focuses on the delay and energy comparison between EDCA and EDCA/CA. The delay here means the average duration from one packet entering the queue until being transmitted. The delay does not include the packet transmission time from the source to the destination. Because the selection of δ and $Nacc$ plays a crucial role on the performance, the second set of the simulation results study the performance by varying δ and $Nacc$. From the experiment, the effect of various δ and $Nacc$ values are demonstrated.

The results of first-set experiments are presented in Fig. 3.2 and Fig. 3.3. Fig. 3.2 shows that when the number of mobile nodes is between 1 and 9, the average packet delay of *AC_VI* in the proposed EDCA/CA is a little bit longer than the original EDCA. This is because packets may suffer from extra queuing delay in the *Accumulation Phase* in EDCA/CA. Besides, the video traffic, AC_VI has lower priority than the voice traffic, AC_VO, in the 802.11e design. The average delay of voice flows could be longer because it needs to wait for longer time after voice traffic finishes its transmission. In our method, the voice traffic would gather more frames once it gains the medium, which lets the voice traffic wait for longer time. However, the difference is small. In addition, the packet delay of *AC_VI* in EDCA/CA is lower than 20 ms, which could still meet the delay requirement of video traffic. When the number of nodes is more than 10, the packet delays of *AC_VO* and *AC_VI* in both EDCA and EDCA/CA drastically increase. The packet delays of *AC_VI* in both EDCA and EDCA/CA go beyond 0.5 $second$ when the number of nodes is larger than 12. Comparing with EDCA, however, the delay of *AC_VI* in EDCA/CA could be reduced among 54% to 62% depending on the number of nodes. The delay of *AC_VO* in EDCA/CA could be reduced among 5% to 56% comparing to the delay in EDCA. This indicates that the proposed EDCA/CA could improve the performance of packet delay in EDCA when when traffic load is heavy.

Fig. 3.3 compares the energy consumption in EDCA and EDCA/CA. It shows that the proposed EDCA/CA could save up to 25% of energy comparing with EDCA. This is because EDCA/CA could reduce the collision probability, which in turn reduces the energy wasted on retransmissions. Fig. 3.3 also indicates that when the number of nodes is bigger than 12, there is no difference in energy consumption. This is because when the network is saturated, the original EDCA would also “accumulate” an amount of buffered frames before real transmission, which is the same as our proposed method, EDCA/CA.

The proposed EDCA/CA should be implemented in an environment in which the traffic data rate is high. If the packet inter arrival time from the application is too long, the proposed method would increase the packet delay since the packets are accumulated until a constant amount of frames are gathered before the channel contention. However, we argue that more and more applications are emerging recently. The data rate of these applications is getting high, such as video on demand (VOD) or voice over IP (VoIP) etc. So our proposed scheme could definitely meet the requirement of these applications.

The results of the second experiment are presented in Figs. 3.4–3.6. Fig. 3.4 illustrates the energy consumption with different $Nacc$ and K_δ values. The δ determines when the *Accumulation Phase* will begin. It depends on K_δ. Smaller K_δ implies that it is more likely to enter the *Accumulation Phase* and suspend its contention for the medium. $Nacc$ determines the duration of *Accumulation Phase*. Larger $Nacc$ incurs longer interval of the phase. The K_δ value of a high priority traffic is supposed to be larger so that it would has less opportunity in contention suspension. The traffic which has more stringent delay bound should also have smaller $Nacc$ value. Smaller $Nacc$ would lead to shorter waiting time during the *Accumulation Phase* in EDCA/CA. Fig. 3.4 shows that the EDCA/CA with $K_\delta = 100$ and $Nacc = 6$ consumes least energy in the simulation.

Figs. 3.5–3.6 present the packet delay of different $Nacc$ and K_δ values. Fig. 3.5 shows that results of *AC_VO* do not deviate a lot, while those of *AC_VI* in Fig. 3.6 are of greater variation with distinct values. Because *AC_VO* has higher priority than *AC_VI*, *AC_VO* with larger $Nacc$ would occupy the medium longer, which indirectly causes *AC_VI* to defer longer. Therefore, delays of *AC_VI* differ more than those of *AC_VO*. Besides, the delay of *AC_VI* is more likely affected by $Nacc$ than by K_δ as shown in Fig. 3.6.

Results in this section suggests that energy consumption is correlated with packet delay. Suspending more transmissions would alleviate the contention or accumulating more frames in one burst, which both lead to lower energy consumption since less collision will happen. On contrast, it would detain frames for a longer time, which means the average packet delay will increase. Delay and energy consumption seem to be the two sides of a coin; one is the tradeoff of the other one. Therefore, the two parameters, $Nacc$ and K_δ, should be carefully selected according to different QoS requirements.

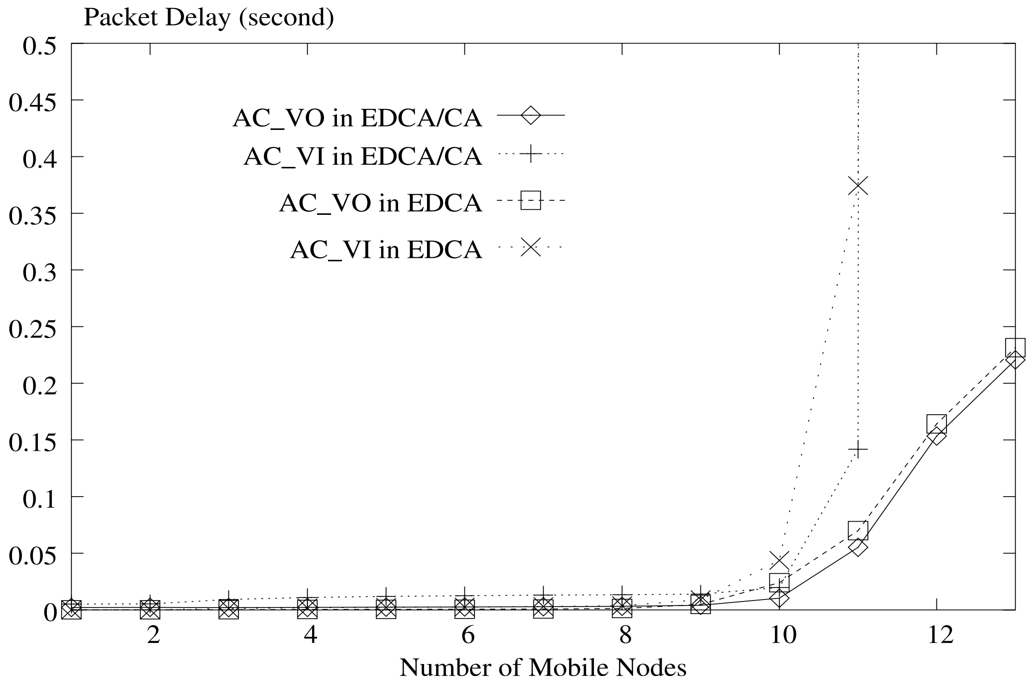

Figure 3.2: Packet delay: comparison of EDCA and EDCA/CA

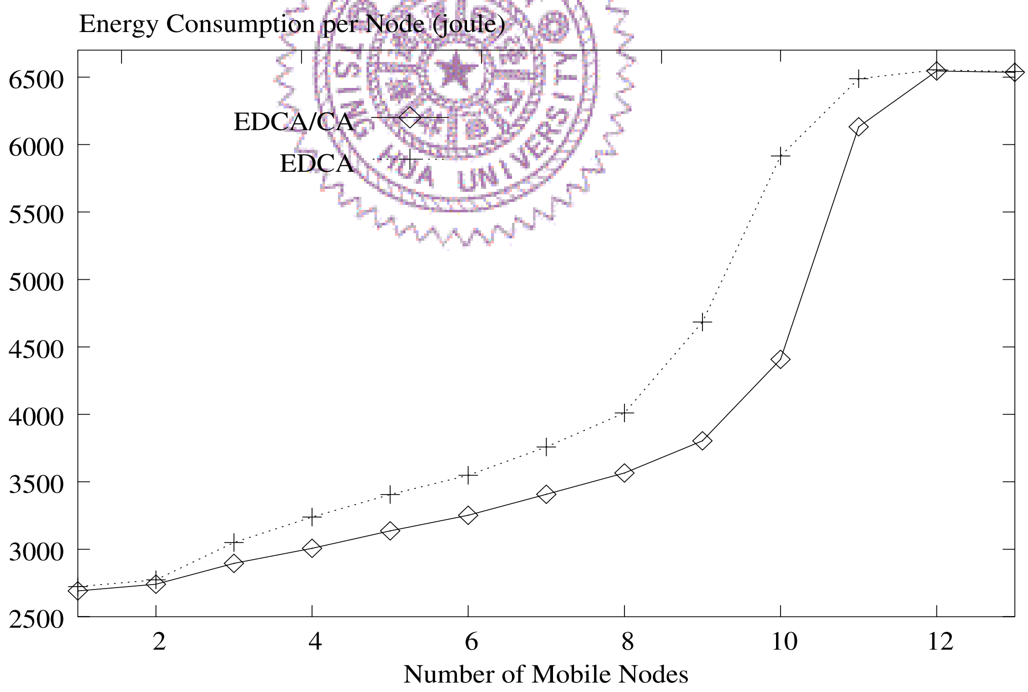

Figure 3.3: Energy consumption: comparison of EDCA and EDCA/CA

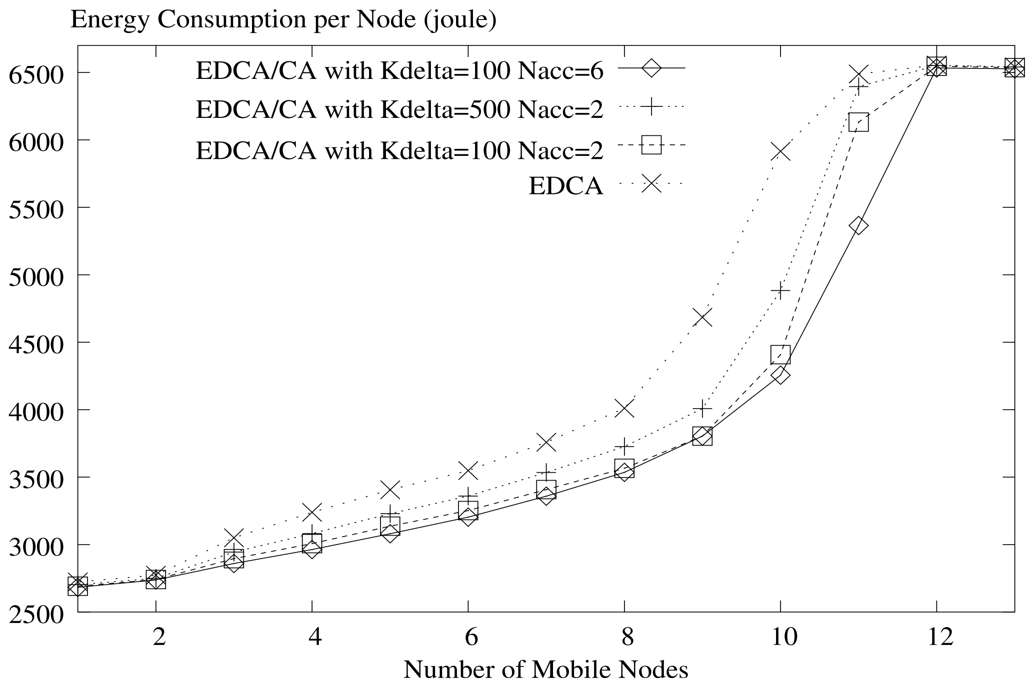

Figure 3.4: Energy consumption: varying δ and $Nacc$

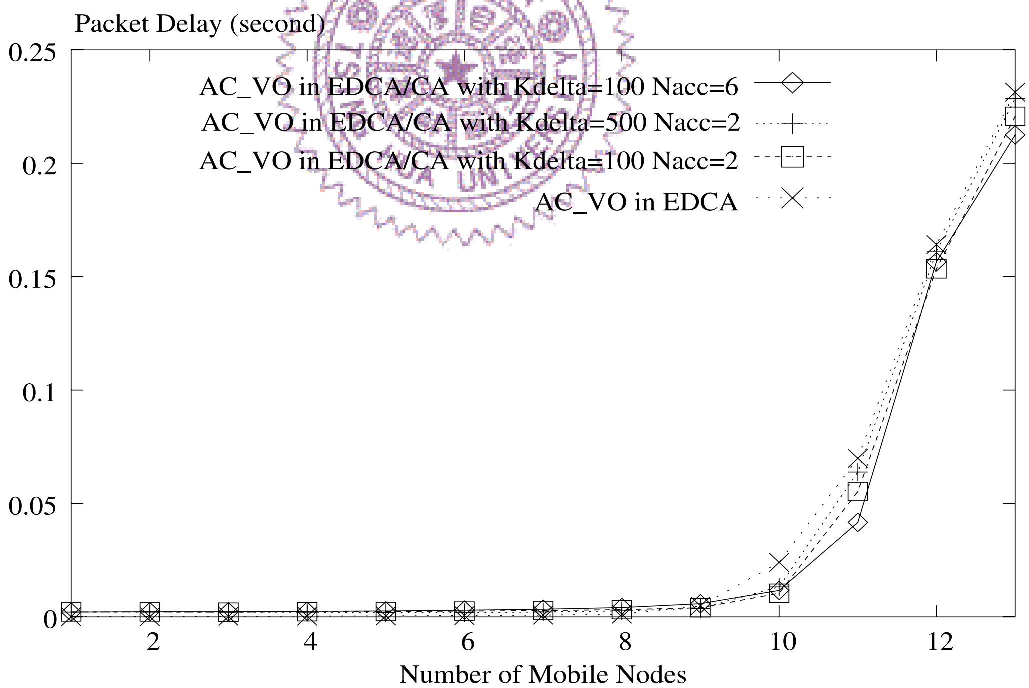

Figure 3.5: Packet delay of *AC_VO*: varying δ and $Nacc$

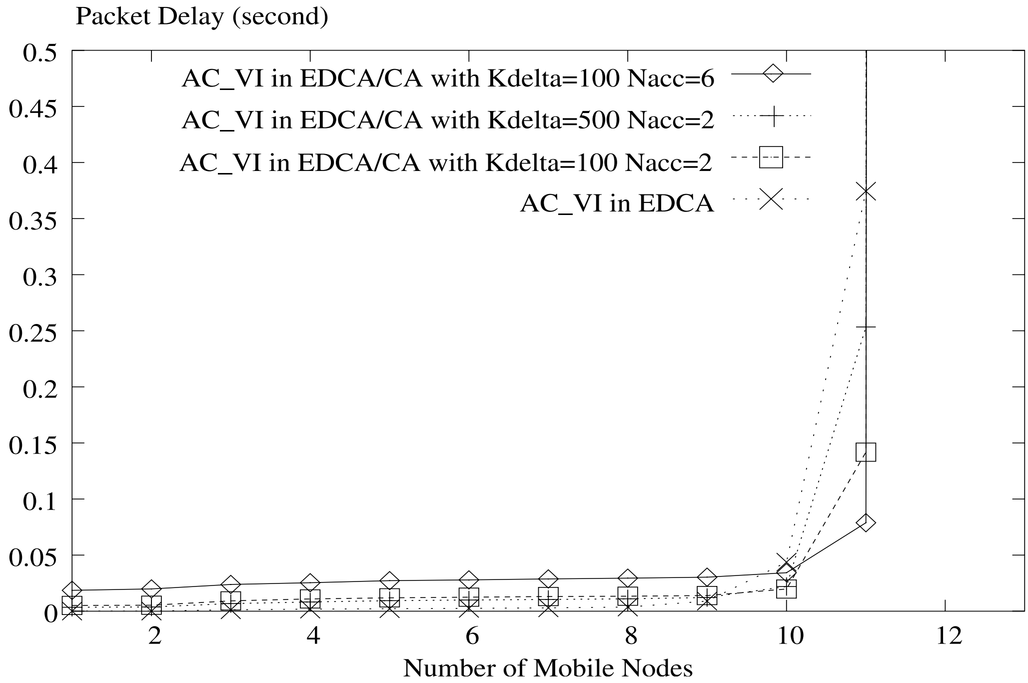

Figure 3.6: Packet delay of *AC_VI*: varying δ and $Nacc$

3.4 Future work

The two newly introduced parameters in our proposed *EDCA/CA* are δ and $Nacc$. The queuing delay of every single frame will be monitored. Once the frame delay supasses δ, then the *Access Category (AC)* will enter the *Accumulation Phase* and suspend its channel contention temporarily until the number of buffered frames equals $Nacc$. δ and $Nacc$ could vary from one AC to another. Larger δ represents an AC is more likely to enter the *Accumulation Phase* and postpone the channel contention. On the other hand, an AC have smaller δ will have fewer chance in contention suspension. For a larger $Nacc$, a station is forced to gather more frames in one transmission burst, which will benifit the medium utilization and also save more energy consumption. However, a larger $Nacc$ will also invoke a longer packet delay, which will violate the QoS requirement of certain applications.

As the simulation results shown in the previous section, various δ and $Nacc$ values will result in different outcomes of delay and energy consumption as well. The packet generation rate and packet size of the application layer also influence the two parameters. Not only the state of a single station will affect the adoption of the two parameters, but also the situations of other competitors as well. For instance, the optimal values for δ and $Nacc$ may be different when the number of users is 3 and 10. So to find out the actual relation between the two parameters and these external factors, such as the traffic types, packet generation rate, or the packet size of the application layer will be the next step of the work.

Although there is a number of research work focusing on the mathematical model on 802.11e, most of the work extends the 802.11 analytical model developed by Giuseppe Bianchi [32]. The extension work studied the collision probability and network throughput based on the model. Majority of the papers neglects the existence of the *Contention Free Burst (CFB)*. So the final throughput will not match actual 802.11e. Besides, few literature work has considered the factors from the application layer. In fact, most of the research simply assumed the network as "satuated"; that is, every single station was trying to contend for the channel anytime. In contrary, what we want to do is to study the behaviors when the network is unsatuated. As a result, there is still a lot of following work to do.

3.5 Summary

The IEEE 802.11e EDCA is contention-based and could lead to serious collisions when traffic load is heavy. This makes EDCA could not guarantee QoS at all time. Collisions would lead to longer packet delay and more retransmissions. Packet delay, however, is important for future multimedia services, such as voice and video applications. Besides, frequent retransmission would result in more contention and more energy consumption, which is a precious resource for portable gadgets lacking constant electricity supply.

In this paper, we propose *Enhanced Distributed Channel Access with Contention Adaption (EDCA/CA)*, a simple yet efficient mechanism to improve EDCA. By only introducing two additional parameters, δ and $Nacc$, the proposed EDCA/CA could outperform the original 802.11e EDCA. Besides, EDCA/CA is fully compatible with EDCA. The main idea of EDCA/CA is to suspend some transmissions when traffic load is heavy. Furthermore, EDCA/CA takes advantage of *CFB*, which is newly proposed in EDCA. *CFB* stands for *Contention Free Burst*. In legacy 802.11 DCF, a station is only allowed to transmit one data frame once it gets the channel. However, 802.11e EDCA permit a user having its frames transmitted continuously without further contention. The total transmission time including the data frames and the corresponding acknowledgements is confined within *TXOPlimit*. The CFB scheme could improve the overall performance of the medium because it gathers more data frames delivered in one burst and ease the intense load. The effect of CFB is evident especially when high traffic load. Through extensive simulation, we demonstrate that the proposed EDCA/CA could significantly improve the energy consumption with minor but acceptable delay deterioration compared with EDCA. In addition, the impact of δ and $Nacc$ is also examined. Results suggest that energy consumption is correlated with packet delay. One is the tradeoff of the other. The two parameters, $Nacc$ and K_δ, should be carefully selected according to different QoS requirements.