CHAPTER 3

IEEE 802.11e EDCA Markov Chain Model

When we start to describe our research, we need to overview the process from the beginning to the end. First, we need to know the relationship between delay and the number of connections. Thus we use a 802.11e EDCA Markov Chain model to find it out. Next step, we use a CAC mechanism constraining the number of connections to avoid over delay caused by too many connections. Then, when voice (VO) and video (VI) traffics from QSTA through 802.11e transmitting to SSQAP, SSQAP considers the delay requirement and the bandwidth which be granted from BS. VO traffics are CBR traffics with constant time and constant bits arrival. If the delay and bandwidth of the VO traffic are enough, SSQAP will forward it. Otherwise it will be dropped. VI traffics are VBR traffics with possible bustness situation occur. Therefore, we use a Token Bucket mechanism to constrain the output to ensure the delay and bandwidth is sufficient. Furthermore, we can estimate the bandwidth to automatically tune the token rate. Finally, we employ a Packet Drop mechanism to improve throughput.

Before we start to describe our 802.11e EDCA Markov Chain model, we have several main parts to stress. We explain our model assumption first, and make a brief introduction. Then we expand on the meanings of states and the transition probabilities in our model.

Finally, we propose the delay and throughput functions and use iterative method to solve our model.

3.1. Model Assumption

We assume that every QSTA could communicate with each other directly. In order to use this model to guarantee the QoS of VO and VI flows in a strict environment. We just assume there are VO and VI flow in our scenarios, because VO and VI are real-time traffic but BK and BE are delay toleration data. All traffic flows with VO use the same Traffic Specification (TSPEC), and all traffic flows with VI also use the same TSPEC. The packet size of VO is different from VI, because the packet of VO is always far smaller than packets of other ACs. For simplify the model we assume that all data are transmitted with RTS/CTS mode. Only the RTS packet will collide with each other, so the collision time is fixed. Markov Chain expresses one flow in a QSTA. Consider the number of QSTA is N. The number of AC flow is defined as N_{AC}.

3.2. Model Introduction

Our Markov Chain model, which is base on [8] and [11], is four-dimensions, the same as [11]. The fourth dimension in our Markov Chain model is similar but not identical to [11]. The main difference is channel state. Other three dimensions are the retry times, recording the last backoff number, and the AIFSN number of different Access Categories.

We propose a Markov Chain model for VO, VI and BK traffic (Figure 3-1). The different traffic use the same Markov Chain model, but the parameter Z_{AC} is different. The Z_{AC} means the probability when it wants to transmit data and others do not. Because the backoff number and AIFSN of each traffic classes are dissimilar, the parameter Z_{AC} is different on each other.

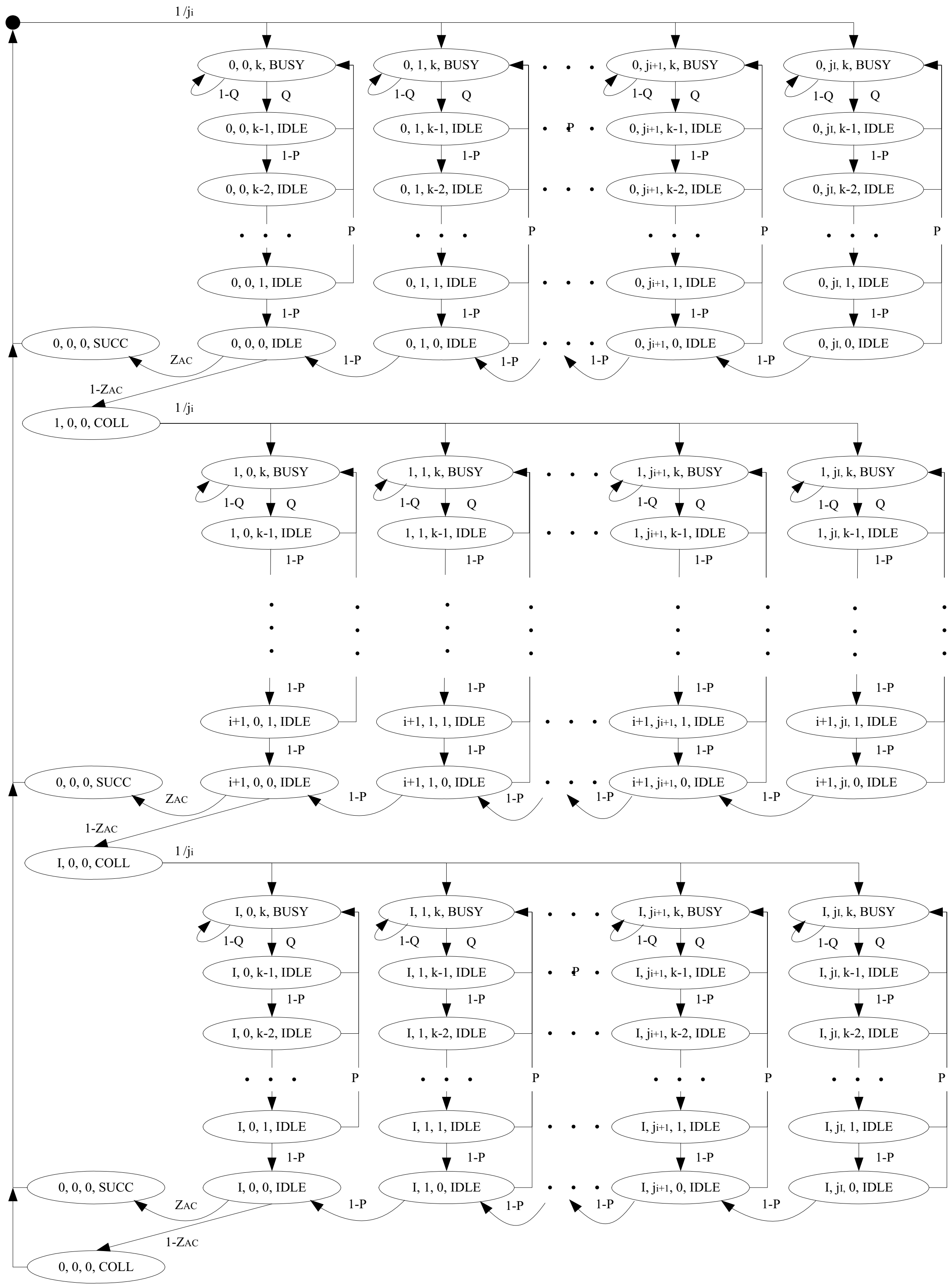

Figure 3-1: The 802.11e EDCA Markov Chain.

3.3. Markov Chain State

We use this four-dimensional process b(t) = { i(t), j(t), k(t), s(t) } with the discrete-time Markov Chain. We let I is the retry limit of 802.11e. i(t) means the first discrete-time stochastic process representing retry counter and it is backoff stage simultaneously. A discrete and integer time scale is adopted: t and t+1 correspond to the beginning of two consecutive slot times. Here one unit of time means one time slot in 802.11e.

The second discrete-time stochastic process is j(t). It represents the backoff number which counts down when the channel is idle after AIFSN. When it counts down to zero, it will try to access the medium. The upper bound of j(t) defined is J_i which depend on the value of retry i(t). $J_{AC,i}$ (J_i) is the CW_{AC} of backoff stage i.

The third discrete-time stochastic process is k(t). It means the AIFSN of the ACs. When the channel sense idle the k(t) starting count down. If before k(t) counts down to zero that senses the channel status is busy, it will reset to the maximum value at next time to count down. Backoff number j(t) starts count down after k(t) counts down to zero.

The last stochastic process s(t) represents the channel state. There are four channel states. One is IDLE, which means the channel is idle at least for a PIFS time. The second is BUSY, which means the channel is sensed busy no matter because collision or data transmitting busy. The third is SUCC, which means when the QSTA transmits data without others want to do. The last is COLL that means the QSTA sand a RTS which collision with others for transmitting data.

3.4. Transition Probability Matrix

After Markov Chain State, we starting describe the transition probability matrix. Here we use the Inter-First Attempting Transmissions time (IFAT) for estimating the channel loading. The IFAT means the interval a packet arrival MAC and try to transmit it at the first time. If the channel is busy for contention, the value of IFAT will be bigger, as Figure 3-2 shows that. In our Markov Chain, the probability of first time try to transmit is state $b_{AC}(0, 0, 0, IDLE)$. We the IFAT is the reciprocal of the probability as follow:

$$IFAT_{AC} = \frac{1}{b_{AC}(0,0,0,IDLE)} \qquad AC = VO, VI \tag{1}$$

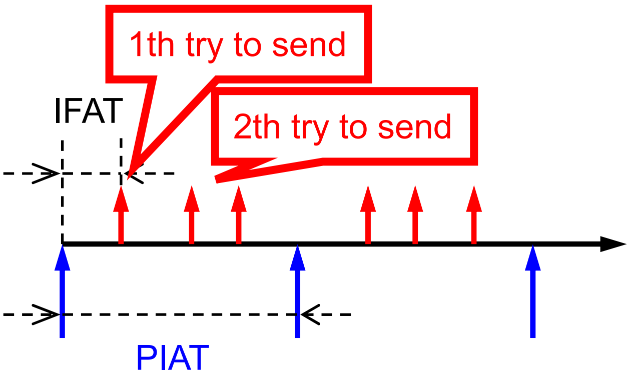

Figure 3-2: The conception of the IFAT and PIAT.

The RATIO is a probability of there is a real packet to transmit in the Packet Inter Arrival Time (PIAT) interval. If the RATIO is bigger than 1, we define the RATIO is 1. That means the preceding packet still in the queue when the next packet arrival MAC and want to transmit. When the RATIO is smaller than 1, we could assume in other times as a virtual packet wait for transmitting. In our model assumption, the BK and BE traffic as a BK traffic and it is fully loading, so the RATIO of BK is 1

$$RATIO_{AC} = \min\left[1,\ \frac{IFAT_{AC}}{PIAT_{AC}}\right] \qquad AC = VO,\ VI$$
$$RATIO_{AC} = 1 \qquad AC = BK \tag{2}$$

There are three mainly probability of the channel state. First, P is the probability from idle to busy when AIFSN or backoff count down. If QSTA senses channel is idle to idle (1-P), it will keep counting down. When it senses channel is idle to busy (P), it will stop count down AIFSN or backoff and wait for changing to idle. If QSTA count down AIFSN and backoff to zero and there is nobody wants to transmit data, the probability is Z and it can transmit data. Otherwise, the probability is 1-Z and it will count down AIFSN k(t) next slot time then try to retransmission. If there is someone transmitting data, the probability is 1-Q, besides other QSTAs will in state b(i,j,k,BUSY) and waiting for the channel state change to idle (Q). When channel state is from busy to idle (Q), QSTA will count down AIFSN k(t) again then continue count down backoff j(t).

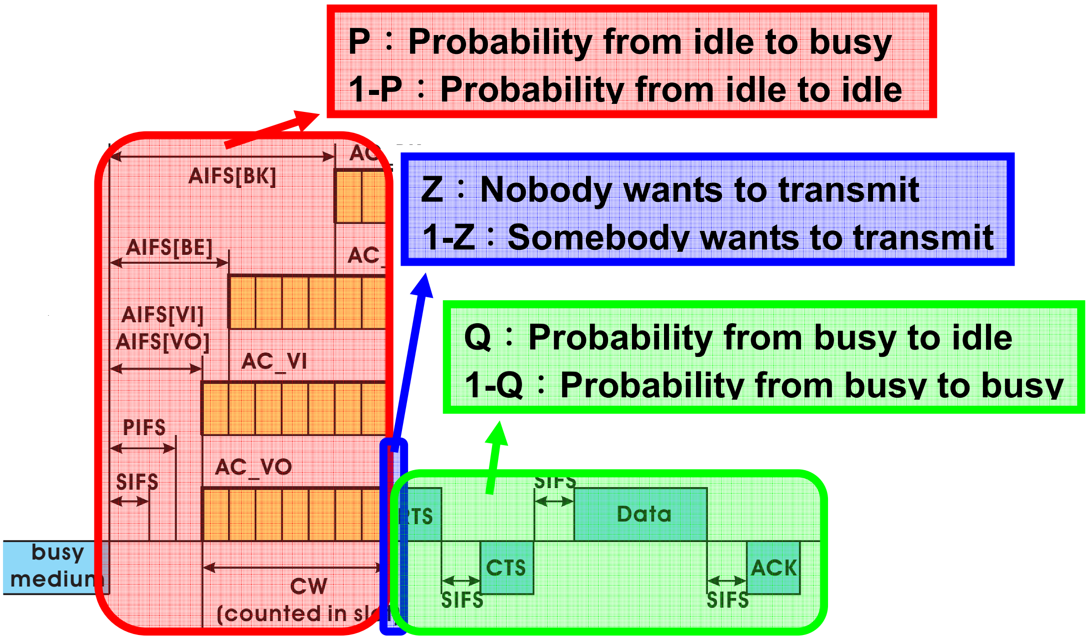

Figure 3-3: The conception of the probability P, Q and Z.

The state $b_{AC}(i,0,0,SUCC)$ and $b(i,0,0,COLL)$ are the actually busy state in itself because transmitting data or collision with others in our Markov Chain model. State $b_{AC}(i,j,k,BUSY)$ means the channel is busy when other QSTA contention or transmitting data not itself. This shows that $\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)$ represents the total busy probability itself. Therefore, Z_{AC} means the probability when it wants to transmit packet which class is what kinds of ACs and others will not as follows:

$$
\begin{aligned}
Z_{VO} = & \left[1-\left(\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)\right)*RATIO_{VO}\right]^{N_{VO}-1} \\
& \left[1-\left(\sum_i b_{VI}(i,0,0,SUCC)+\sum_i b_{VI}(i,0,0,COLL)\right)*RATIO_{VI}\right]^{N_{VI}} \\
& \left[1-\left(\sum_i b_{BK}(i,0,0,SUCC)+\sum_i b_{BK}(i,0,0,COLL)\right)\right]^{N_{BK}}
\end{aligned}
\qquad (3)
$$

$$Z_{VI}=\left[1-\left(\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)\right)*RATIO_{VO}\right]^{N_{VO}}$$
$$\left[1-\left(\sum_i b_{VI}(i,0,0,SUCC)+\sum_i b_{VI}(i,0,0,COLL)\right)*RATIO_{VI}\right]^{N_{VI}-1} \quad (4)$$
$$\left[1-\left(\sum_i b_{BK}(i,0,0,SUCC)+\sum_i b_{BK}(i,0,0,COLL)\right)\right]^{N_{BK}}$$

$$Z_{BK}=\left[1-\left(\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)\right)*RATIO_{VO}\right]^{N_{VO}}$$
$$\left[1-\left(\sum_i b_{VI}(i,0,0,SUCC)+\sum_i b_{VI}(i,0,0,COLL)\right)*RATIO_{VI}\right]^{N_{VI}} \quad (5)$$
$$\left[1-\left(\sum_i b_{BK}(i,0,0,SUCC)+\sum_i b_{BK}(i,0,0,COLL)\right)\right]^{N_{BK}-1}$$

As previously mentioned, RATIO is the probability of there is a really packet to transmit in PIAT. We can not ensure VO and VI traffic is full loading. Therefore, $\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)$ should multiply the RATIO to estimate the really busy probability. The Z_{AC} is the viewpoint from a QSTA. If the QSTA wants to transmit VO traffics that means there are N_{vo}-1 QSTAs want to transmit VO too, the exponent is N_{vo}-1. Thus, the other class exponent is N_{AC}.

After getting the probability Z, now we estimate the P_{BUSY} which is busy probability. The P_{BUSY} is similar to Z, but P_{BUSY} is the channel status in network. Thus, the exponent is N_{AC}. After $1-\left(\sum_i b_{AC}(i,0,0,SUCC)+\sum_i b_{AC}(i,0,0,COLL)\right)*RATIO_{AC}$ to the power of N_{AC} and multiply other AC is the channel idle probability. Therefore, we make 1 subtract the idle probability to represent the P_{BUSY}.

$$\begin{aligned} P_{BUSY} = 1 - & \left[1-\left(\sum_i b_{VO}(i,0,0,SUCC)+\sum_i b_{VO}(i,0,0,COLL)\right)*RATIO_{VO}\right]^{N_{VO}} \\ & \left[1-\left(\sum_i b_{VI}(i,0,0,SUCC)+\sum_i b_{VI}(i,0,0,COLL)\right)*RATIO_{VI}\right]^{N_{VI}} \\ & \left[1-\left(\sum_i b_{BK}(i,0,0,SUCC)+\sum_i b_{BK}(i,0,0,COLL)\right)\right]^{N_{BK}} \end{aligned} \tag{6}$$

When we estimate the P_{BUSY}, we still need to know the busy is for transmitting what kinds of traffic. $P_{VO,BUSY}$ indicates the channel busy is for transmitting VO. We assume there are N_{VO} want to transmit voice and someone is success. The probability represents as $C_1^{N_{VO}} * \sum_i b_{VO}(i,0,0,SUCC)$. At the same time, the probability of the others do not want to transmit packets is Z_{VO}. Then we should multiply the $RATIO_{VO}$ to estimate the probability of it really occurs. The same reasoning, we can calculation the probability of the other classes. Finally, we can let P_{BUSY} subtract the transmission probability of the all classes to get the collision probability $P_{C,BUSY}$.

$$\begin{cases} P_{VO,BUSY} = C_1^{N_{VO}} * \sum_i b_{VO}(i,0,0,SUCC) * Z_{VO} * RATIO_{VO} \\ P_{VI,BUSY} = C_1^{N_{VI}} * \sum_i b_{VI}(i,0,0,SUCC) * Z_{VI} * RATIO_{VI} \\ P_{BK,BUSY} = C_1^{N_{BK}} * \sum_i b_{BK}(i,0,0,SUCC) * Z_{BK} \\ P_{C,BUSY} = P_{BUSY} - P_{VO,BUSY} - P_{VI,BUSY} - P_{BK,BUSY} \end{cases} \tag{7}$$

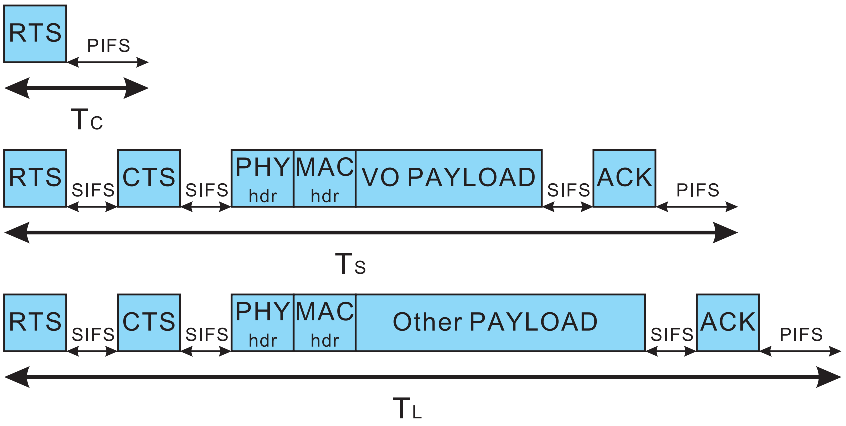

Figure 3-4: Transmission Time for COLL, SMALL, and LARGE.

Figure 3-4 shows the transmission time for different event. T_{LARGE} means the transition time of a packet with VI, BE, or BK. T_{SMALL} means the transition time of a packet with VO. T_{COLL} means the collision time of RTS packet. We define H = MAChdr + PHYhdr. δ is the propagation delay. We have

$$\begin{cases} T_C = & RTS + PIFS + \delta \\ T_S = & RTS + SIFS + \delta + CTS + SIFS + \delta + H + \\ & PAYLOAD_S + SIFS + \delta + ACK + PIFS + \delta \\ T_L = & RTS + SIFS + \delta + CTS + SIFS + \delta + H + \\ & PAYLOAD_L + SIFS + \delta + ACK + PIFS + \delta \end{cases} \tag{8}$$

Then, we can obtain the average transmission time $\overline{T}$ which is the different transmission time multiply the occur probability and add them together.

$$\overline{T} = \left[T_S * \left(\frac{P_{S,BUSY}}{P_{BUSY}}\right) + T_L * \left(\frac{P_{L,BUSY}}{P_{BUSY}}\right) + T_C * \left(\frac{P_{C,BUSY}}{P_{BUSY}}\right) \right] \tag{9}$$

After we calculate the average transmission time $\overline{T}$. We can estimate the transition probabilities from BUSY to IDLE (defined as Q) from the transmission time. The transition probabilities of Q are written as follows:

$$Q = P(IDLE|BUSY) = \frac{1}{\overline{T}} \tag{10}$$

3.5. Delay, Throughput and Packet Drop rate Calculation

The MAC delay time (MD) is from packet arrival MAC to the packet can be transmitted. In the Markov Chain model, each probability of transmission successful in retry i(t) is b(i,0,0,SUCC). In addition, we need to consider when the next packet arrival but the channel is busy. This situation will let the new packet waiting for channel status change to idle to entry Markov Chain model. $\frac{\overline{T}}{2} * p_{BUSY}$ represents this residual time. In addition, we need to consider the really packets in MAC ($RATIO_{AC}$). Thus, we can estimate the delay time as follows:

$$MD_{AC_i} = \left(\frac{1}{b_{AC_i}(i,0,0,SUCC)} + \frac{\overline{T}}{2} * P_{BUSY} \right) * RATIO_{AC} \qquad AC = VO, VI \tag{11}$$

After we obtain the each MD in retry i(t), we still need to know the probability of each transmission. If the packet be transmitted and successfully at the first time, the probability is Z_{AC} which we regard as a weight. Another packet tries to transmit at the first time, but it is collision with another packet. When it transmission successful at next time, the probability is $(1-Z_{AC})*Z_{AC}$. And so on, we can obtain the probability is $Z_{AC} * (1 - Z_{AC})^i$ in each i(t). We normalize $\sum_i Z_{AC} * (1 - Z_{AC})^i$ to 1 and base on the formula of the geometric progression as follows, we can compute the average MD as follows:

$$\frac{a_1\left(1-r^n\right)}{1-r} \quad ➔ \quad \frac{Z_{AC}\left[1-\left(1-Z_{AC}\right)^{I+1}\right]}{\left[1-\left(1-Z_{AC}\right)\right]} \tag{12}$$

$$MD_{AC}=\sum_i MD_{AC_i} * \frac{Z_{AC} * (1-Z_{AC})^i}{\frac{Z_{AC}\left[1-\left(1-Z_{AC}\right)^{I+1}\right]}{\left[1-\left(1-Z_{AC}\right)\right]}} \qquad AC=VO,\ VI \tag{13}$$

$$MD_{AC}=\sum_i MD_{AC_i} * \frac{Z_{AC} * (1-Z_{AC})^i}{1-\left(1-Z_{AC}\right)^{I+1}} \qquad AC=VO,\ VI \tag{14}$$

We can obtain the packet drop rate (PD) which is b(I,0,0,COLL) in Markov Chain model. But we still consider the really packets in MAC ($RATIO_{AC}$). So we can get the PD from multiply these two parameters.

$$PD_{AC}=b_{AC}\left(I,0,0,COLL\right) * RATIO_{AC} \qquad \mathrm{AC}=\mathrm{VO},\mathrm{VI},\mathrm{BK} \tag{15}$$

Finally we estimate the throughput. In addition to consider PD, we need to think over the channel status. As MD or PD, considering the really packets in MAC ($RATIO_{AC}$). Therefore, we can obtain the throughput as follows:

$$Throughput_{AC}=\frac{SIZE_{AC} * \left(1-PD_{AC}\right)}{IFAT_{AC}} * RATIO_{AC} \quad \mathrm{AC}=\mathrm{VO},\mathrm{VI},\mathrm{BK} \tag{16}$$

3.6. Model Validation

We will validate our model for comparing the MD, throughput and PD with the simulator Qualnet. But actually, we just need to use VI MD to compute the delay from QSTA to BS. QoS guarantee is for real-time traffics as VO and VI traffics then VO traffic is CBR which without burstness, so we just concern about the delay of VI traffic. Thus, the VO (UGS) and VI (rtPS) are real-time traffics which need to reach the QoS guarantee. The BE (nrtPS) and BK (Best effort) are delay tolerant traffics, so we just use VO and VI for simulating.

Table 3-1: System Parameters.

VO AIFSN	2	**VI AIFSN**	2
VO CWmin	3	**VI CWmin**	7
VO CWmax	7	**VI CWmax**	5
SIFS	10 μs	**Bit rate**	11 Mbps
PIFS	30 μs	**Retry Limit**	4
SLOT	20 μs	**Propagation Delay**	1 μs

Table 3-2: TSPEC for VO and VI.

TSPEC	**VoIP (G.729A)**	**Video**
Mean rate	13.02 kbps	381 kbps
Packet size	800 bits	16000 bits
Inter-arrival time	60 ms	42 ms

The MAC and PHY parameters are listed in Table 3-1 and the TSPEC we used are in Table 3-2. In order to reduce the transmitting frequency of VO flows, we use six VO frames as a packet. Each VO frame length is 80 bits. The IP/UDP/RTP header is 320 bits. Coding rate is 8 kbps. So the mean data rate without silence-compression is about 13 kbps. About the VI, we use 381 kbps which is the same as 3G.

3.6.1. 802.11e MAC Delay

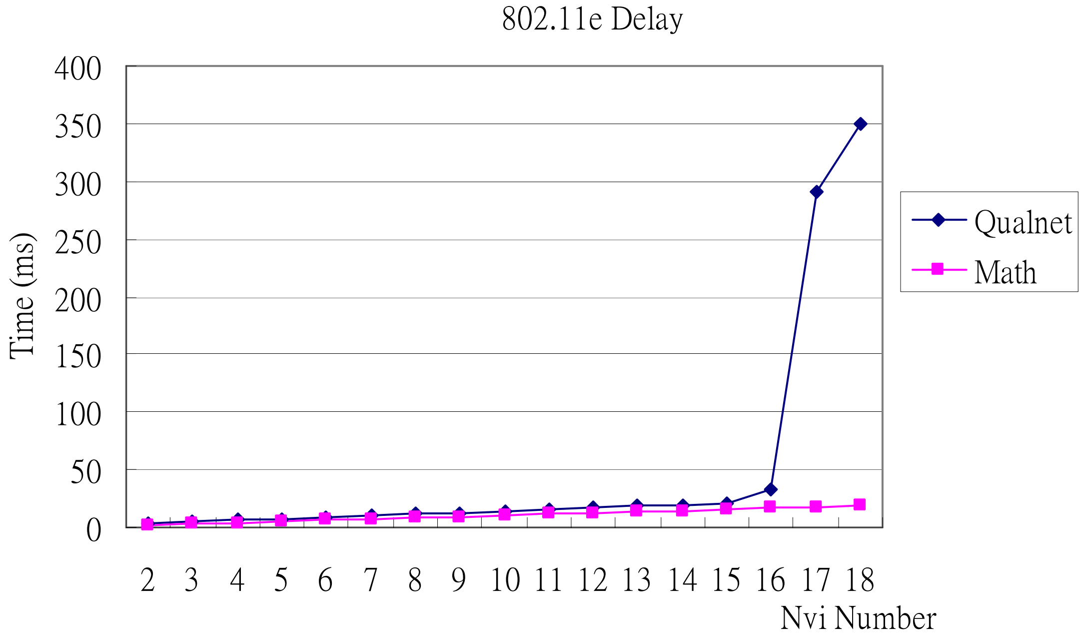

Figure 3-5: Scenario 1 – MAC Delay time (N_{VI}).

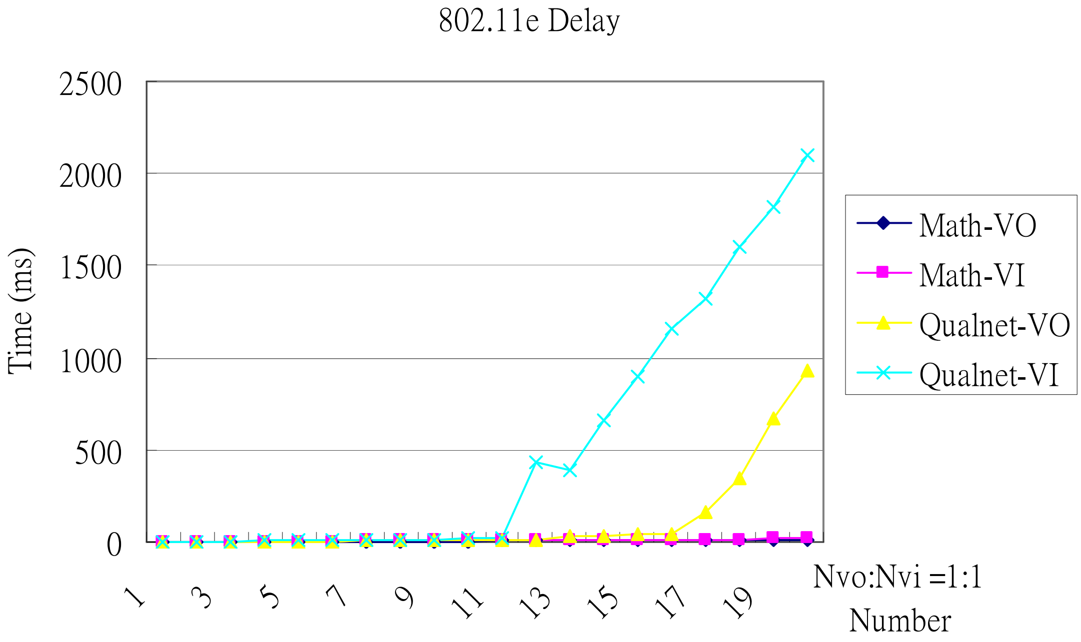

Figure 3-6: Scenario 2 – MAC Delay time (N_{VO} : N_{VI} = 1 : 1).

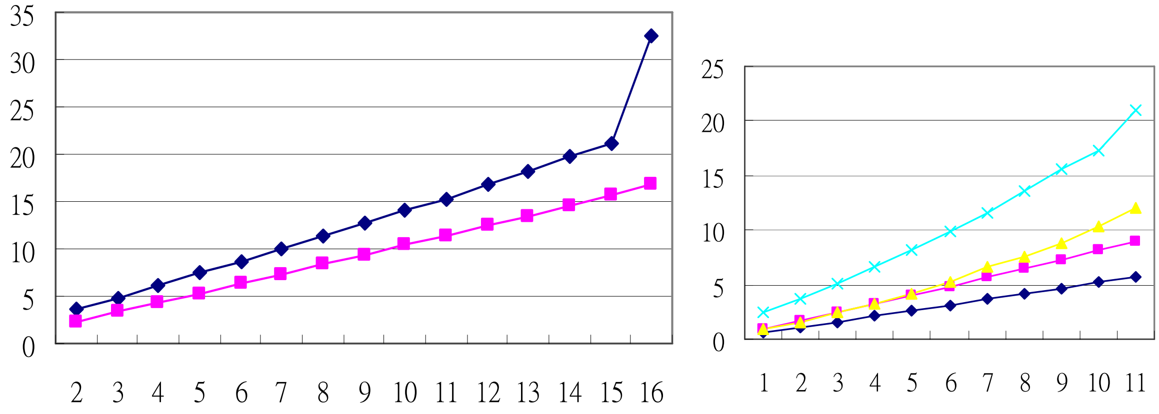

Figure 3-7: Enlarging – MAC Delay time (N_{VI}) ($N_{VO} : N_{VI} = 1 : 1$).

In scenario 1, there are just VI traffics waiting for transmitting to SSQAP. In scenario 2, we consider the VO and VI traffics and the rate of N_{VO} and N_{VI} is 1:1. The simulation time is 30 seconds (default). All parameters are the same in our Math (Markov Chain) model and in Qualnet.

The MD result of our model is linear and smaller than Qualnet, because there is no packet queue and transmission time in our Markov Chain, but there is in Qualnet. Thus we can obtain the rate of the Markov Chain and Qualnet. We will use the information to guarantee QoS later.

3.6.2. 802.11e Packet Drop rate & Throughput

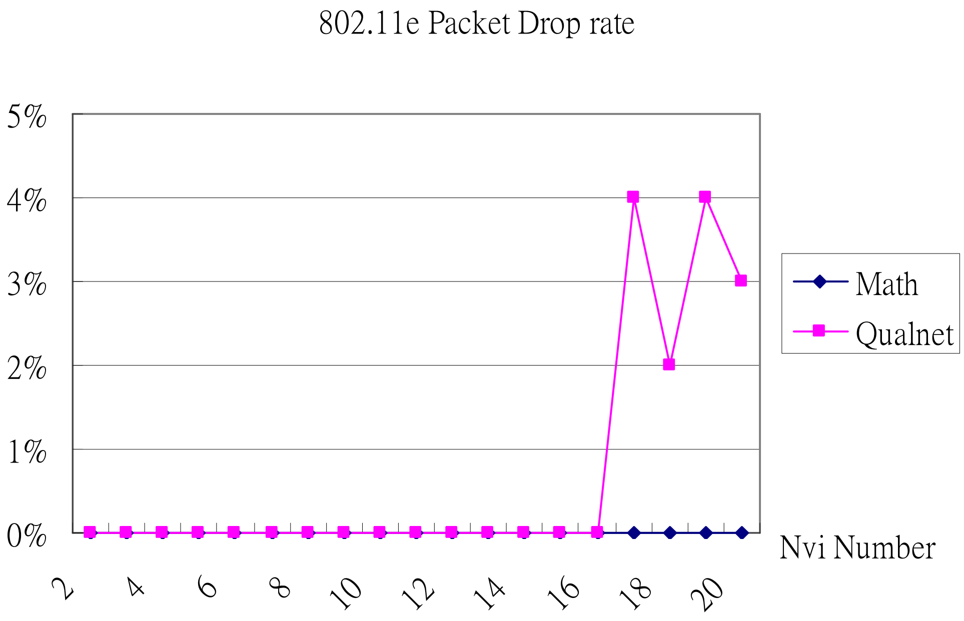

Figure 3-8: Packet Drop rate (N_{VI}).

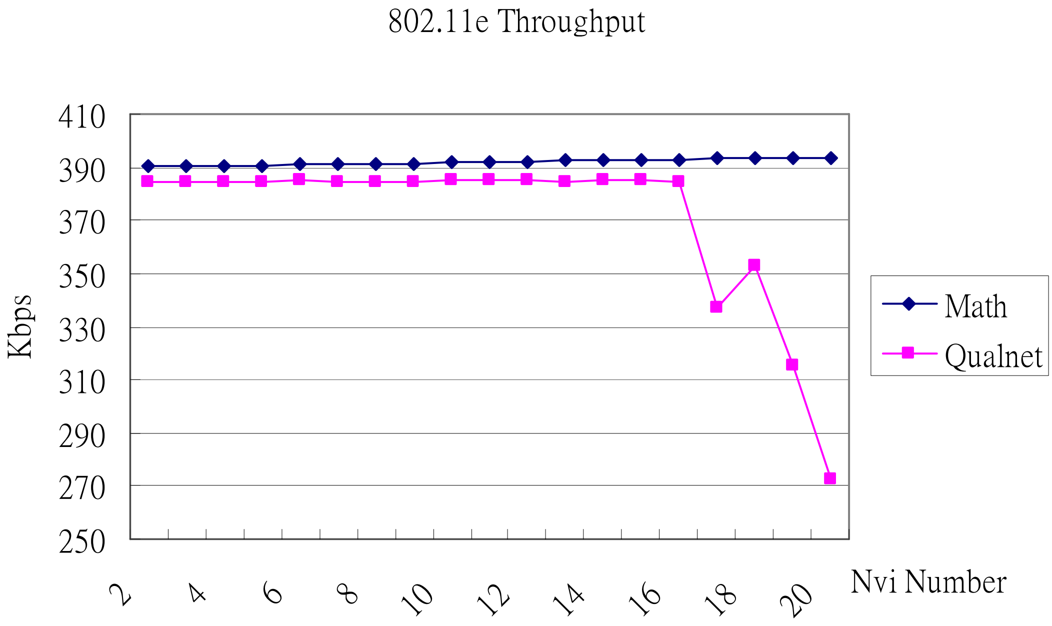

Figure 3-9: Throughput (N_{VI}).

As previously mentioned, SSQAP has a packet queue in Qualnet but we do not. If the loading is more and more hardly, the queue will be full and packets will be drop. Thus, from Figure 3-8 and Figure 3-9 we can assume the queue is full when N_{VI}=17 and packets be dropped. Thus, the throughput decreases when packets start to drop.