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The Performance Analysis of Direct/Cooperative Transmission to Support QoS in WLANs

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Abstract. In the past decades, cooperative communications schemes have gained significant attention in wireless networks. The cooperative scheme leads to longer transmission time which can considerably degrade the system performance. We evaluate the saturation throughput and saturation delay of the Markov chain model with direct/cooperative schemes to support QoS in WLANs. Simulation results show that differentiating the contention window size is better than differentiating the arbitration interframe space in terms of throughput and delay.

Keywords: cooperative scheme, throughput, delay, Markov chain model, QoS, WLANs

1. Introduction

In recent years, the cooperative communications market is experiencing an explosive growth. With the introduction of relays, an auxiliary channel, the relay channel to the direct channel between the source and destination can be generated. That is, the relays help forwarding the signal from the source to the destination [1]. As a result, spatial diversity which ameliorates the frame error rate is generated via the help of relay channel. On the other hand, cooperative scheme leads to longer transmission time which can considerably degrade the system performance. There have been many performance analyses of the cooperative communication systems. Yan Zhu et al [2] showed the effectiveness of utilizing collaborative relays in a large-scale network is penalized by the elevated level of interference. G. Jakllar et al [3] showed that virtual multiple-input single-output (MISO) transmissions can improve the performance and be robustness to link failures due to mobility and interference and the advantage of using virtual antenna arrays is it does not require and additional hardware. Zhiguo Ding et al [4] proposed a spectrally efficient strategy for cooperative multiple access systems in multiple-users environment and it can achieve more robust performance than the direction transmission. K. Lee et al [5] focused on the concept of power consumption and examined the performance of heterogeneous cooperative networks with the source that do not act as relays and relays that are dedicated to relaying functions with concern about power consumption. Most of research mainly focused on the designs of cooperative protocol schemes and how to gain benefits of spatial diversity based on information theory. In order to evaluate the system performance, a suitable analytic model that combines the traditional direction transmission and the cooperative transmission from the medium access control (MAC) perspectives should be exploited and with the population of multimedia applications, including the transport of voice, audio and video over WLANs, there is a clear need to support quality of service (QoS) guarantees. In this paper, we utilize the Markov chain model with direct/cooperative transmission scheme to support QoS guarantees from the MAC perspectives to analyze the saturation throughput and saturation delay.

The rest of this paper is organized as follows. An overview of the system model is depicted in Section II. The performance analysis of the model is depicted in the Section III. The simulation results are shown in Section IV. Finally, Section V gives the conclusions.

2. The System Model

To analyze the performance of the Markov chain model, we follow the considerations of [11]. We assume a fixed number Ni of contending stations in the network and a given station in the priority i class (i = 0, 1, ... , n-1). Let b(*i*, *t*) be the stochastic process representing the backoff timer of a given station at slot time t (note that the backoff timer is stopped when the station senses that channel is busy). The value of the backoff timer is uniformly chosen in the range (0, $W_{i,j-1}$) and depends on the station's backoff stage *j*. For convenience, we define that

$$W_{i,j} = \begin{cases} 2^j CW_{i,min} & 0 \le j < m \\ CW_{i,max} & m \le j \le m+r \end{cases} \tag{1}$$

where $CW_{i,min}$ is the minimum contention widow for the priority *i* class and $CW_{i,max}$ is the maximum contention widow for the priority *i* class, and *m* is the maximum backoff stage. Moreover, let s(*i*, *t*) be the stochastic process representing the backoff stage *j* of the station at time t. On this condition, we can describe the state of each station in the priority *i* class is as {*i*, *j*, *k*}, where *j* stands for the backoff stage and *k* stands for the backoff timer.

There is another state in our model, additional idle state, denoted by {*i*, -1}. The backoff procedure is activated whenever a station has a frame to transmit and senses the channel is busy or whenever the transmitting station infers a failed transmission. If the station verifies its current transmission is successful and senses the channel is idle for arbitration inter-frame spacing in priority *i* class (AIFS[*i*]) duration, it enters into the {*i*, −1} state. If the station is at {*i*, -1} state, whenever it senses the channel is idle for AIFS[*i*] duration, it transmits its frame without entering the backoff procedure.

The state transition diagram of the Markov chain model in the priority *i* class shown in Fig. 1 has the following transition probabilities:

The station transmits its frame without entering the backoff procedure if it senses that its previous transmission was successful and the channel is idle for AIFS[*i*] duration.

$$P\left\{i,-1\middle|i,-1\right\}=\left(1-P_{i,dir}\right)\left(1-P_{i,b}\right). \tag{2}$$

The station defers the transmission of a new frame and enters stage 0 of the backoff procedure if it detects a collision occurred or it senses the channel is busy.

$$P\left\{i,0,k\middle|i,-1\right\}=\left(P_{i,b}+P_{i,dir}-P_{i,b}P_{i,dir}\right)\big/W_{i,0},\ 0\le k\le W_{i,0}-1. \tag{3}$$

The backoff timer is stopped when the station senses that channel is busy.

$$P\left\{i,j,k\middle|i,j,k\right\}=P_{i,b},\ 0\le j\le m+r,\ 0\le k\le W_{i,j}-1. \tag{4}$$

The backoff timer decreases when the station senses that the channel is idle.

$$P\left\{i,j,k\middle|i,j,k+1\right\}=1-P_{i,b},\ 0\le j\le m+r,\ 0\le k\le W_{i,j}-2. \tag{5}$$

The station chooses a backoff delay of stage 0 if its current transmission was successful and it senses that the channel is busy when it tries to transmit a new frame.

$$\begin{aligned}P\left\{i,0,k\middle|i,j,0\right\}&=\frac{\left(1-P_{i,dir}\right)P_{i,b}}{W_{i,0}},\ 0\le j\le \ell-1,\ 0\le k\le W_{i,0}-1.\\ P\left\{i,0,k\middle|i,j,0\right\}&=\frac{\left(1-P_{i,coop}\right)P_{i,b}}{W_{i,0}},\ \ell\le j\le m+r-1,\ 0\le k\le W_{i,0}-1.\end{aligned} \tag{6}$$

Where ℓ is the backoff stage to distinguish the strategy adopting cooperative transmission, the parameters $P_{i,dir}$ is the probabilities in the priority *i* class for receiving incorrect frame at the destination via the traditional direction transmission, $P_{i,b}$ is the probability that the station in the priority *i* class senses that the channel is busy.

The station enters into the {*i*, -1} state if it verifies its current transmission is successful and senses the channel is idle for AIFS[*i*] duration.

$$\begin{aligned}P\left\{i,-1\middle|i,j,0\right\}&=\left(1-P_{i,dir}\right)\left(1-P_{i,b}\right),\ 0\le j\le \ell-1.\\ P\left\{i,-1\middle|i,j,0\right\}&=\left(1-P_{i,coop}\right)\left(1-P_{i,b}\right),\ \ell\le j\le m+r-1.\end{aligned} \tag{7}$$

The station choices a backoff delay of next stage *j* after an unsuccessful transmission at stage *j*−1.

$$\begin{aligned}P\left\{i,j,k\middle|i,j-1,0\right\}&=P_{i,dir}\big/W_{i,j},\ 1\le j\le \ell.\\ P\left\{i,j,k\middle|i,j-1,0\right\}&=P_{i,coop}\big/W_{i,j},\ \ell+1\le j\le m+r.\end{aligned} \tag{8}$$

When the station has reached the last stage of backoff procedure, it would drop the current frame and enter {*i, 0, k*} state if it detects its current transmission is still failed and the channel is busy during an AIFS[*i*] duration.

$$P\{i,0,k|i,m+r,0\} = P_{i,b}/W_{i,0},\ 0 \le k \le W_{i,0}-1. \tag{9}$$

When the station has reached the last stage of backoff procedure, it would drop the current frame and enter {*i*, −1} state if it detects its current transmission is still failed and the channel is idle for AIFS[*i*] duration.

$$P\{i,-1|i,m+r,0\} = 1-P_{i,b}. \tag{10}$$

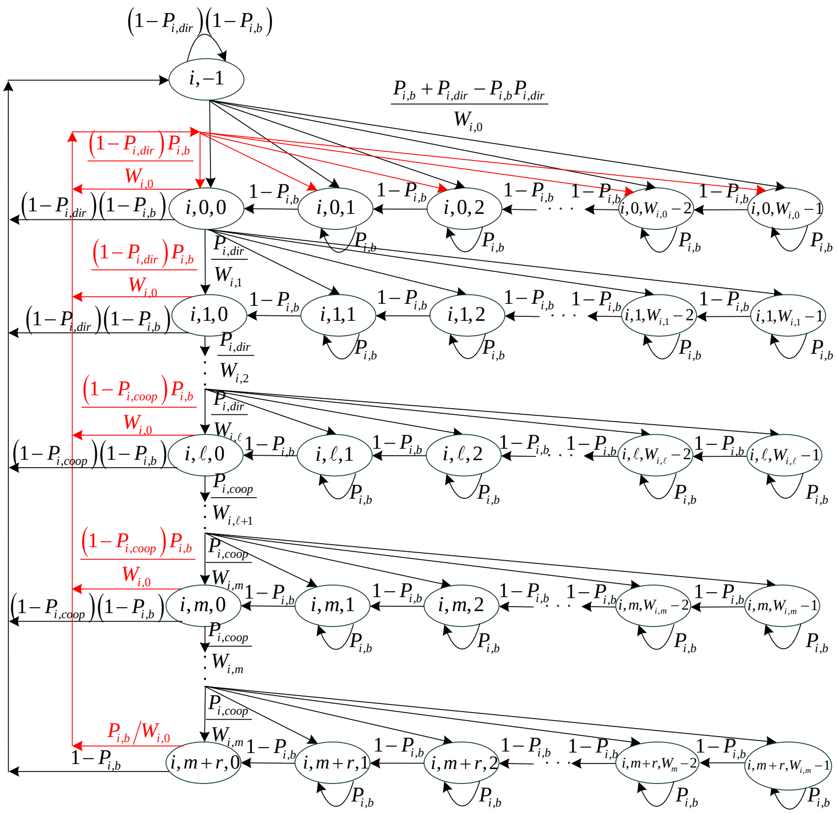

Fig. 1. Markov chain model with direct/cooperative strategy for the priority i

The parameters $P_{i,dir}$ and $P_{i,coop}$ are the probabilities in the priority *i* class for receiving incorrect frame at the destination via the traditional direction transmission and the cooperative transmission, respectively. Note that the unsuccessful reception of frames at the destination is considered to result from either the frame collision or the channel noise. Thus, the parameters $P_{i,dir}$ and $P_{i,coop}$ can be expressed as

$$P_{i,dir} = 1-\left(1-FER_{dir}\right)\left(1-P_{i,c}\right),$$
$$P_{i,coop} = 1-\left(1-FER_{coop}\right)\left(1-P_{i,c}\right), \tag{11}$$

where $P_{i,c}$ is the probability that the transmitted frame collides for the priority i class. FER_{dir} and FER_{coop} are the frame error rates at the destination via the traditional direction transmission and the cooperative transmission, respectively.

We have to calculate the probability that a station in the priority i class is at state $\{i,j,k\}$.

Let $b_{i,j,k} = \lim_{t\to\infty} P\{s(i,t)=j, b(i,t)=k\}$ be the stationary distribution of the Markov chain [6]. In steady-state we have following relations:

$$b_{i,j,0} = P_{dir}^{j} b_{i,0,0},\quad 0 \le j \le \ell.$$
$$b_{i,j,0} = P_{dir}^{\ell} P_{coop}^{j-\ell} b_{i,0,0},\quad \ell+1 \le j \le m+r. \tag{12}$$

$$b_{i,j,k} = \frac{1}{1-P_{i,b}} \frac{W_{i,j}-k}{W_{i,j}} b_{i,j,0}. \tag{13}$$

$$b_{i,-1} = \frac{1-P_{i,b}}{P_{i,b}+P_{i,dir}-P_{i,b}P_{i,dir}} b_{i,0,0}. \tag{14}$$

Let τ_i be the probability that a station in the priority i class transmits its frame during a slot time. A station in the priority i class transmits its frame when its backoff timer reaches zero, regardless of the backoff stage, i.e. the station is at any of the $b_{i,j,0}$ states or at the $b_{i,-1}$ state. Therefore, we have

$$\tau_i = b_{i,-1} + \sum_{j=0}^{m+r} b_{i,j,o}$$
$$= \left(\frac{1-P_{i,b}}{P_{i,b}+P_{i,dir}-P_{i,b}P_{i,dir}} + \frac{1-P_{i,dir}^{\ell+1}}{1-P_{i,dir}} + P_{i,dir}^{\ell} P_{i,coop} \frac{1-P_{i,coop}^{m+r-\ell}}{1-P_{i,coop}}\right) b_{i,0,0} \tag{15}$$

Let N_i (i = 0, 1, ..., n− 1) denote the number of station in the priority i class and P_t denote the probability that there is at least one transmission in a slot time, i.e., there is at least one station transmits during a slot time. Therefore, we have

$$P_t = 1-\prod_{h=0}^{n-1}\left(1-\tau_h\right)^{N_h}. \tag{16}$$

Let $P_{i,s}$ denote the probability that the transmission is successful during a slot time for the priority i class, i.e., a transmission is assumed to be successful when only one station transmits. So we have

$$P_{i,s} = n_i \tau_i \left(1-\tau_i\right)^{N_i-1} \prod_{h=0,h\ne i}^{n-1}\left(1-\tau_h\right)^{N_h}. \tag{17}$$

Let $P_{i,b}$ be the probability that the station in the priority i class senses that the channel is busy when it is trying to decrease its backoff timer in a slot time. The probability $P_{i,b}$ that the station in the priority i class senses that the channel is busy is given by

$$P_{i,b} = 1-\left(1-\tau_i\right)^{N_i-1} \prod_{h=0,h\neq i}^{n-1} \left(1-\tau_h\right)^{N_h}. \tag{18}$$

Moreover, let us introduce the parameter $P_{i,r}$ that is the probability for the priority i class of the traditional direction transmission considering at least one transmission happens. Thus, we have

$$\begin{aligned} P_{i,r} &= \frac{b_{i,-1}+\sum_{h=0}^{\ell-1} b_{i,h,0}}{b_{i,-1}+\sum_{j=0}^{m+r} b_{i,j,0}} \\ &= \frac{\dfrac{1-P_{i,b}}{P_{i,b}+P_{i,dir}-P_{i,b}P_{i,dir}}+\dfrac{1-P_{i,dir}^{\ell}}{1-P_{i,dir}}}{\dfrac{1-P_{i,b}}{P_{i,b}+P_{i,dir}-P_{i,b}P_{i,dir}}+\dfrac{1-P_{i,dir}^{\ell+1}}{1-P_{i,dir}}+P_{i,dir}^{\ell}P_{i,coop}\dfrac{1-P_{i,coop}^{m+r-\ell}}{1-P_{i,coop}}} \end{aligned} \tag{19}$$

3. Performance Analysis

In this section, the purpose of our analysis is to evaluate the saturation throughput and the delay performances of Markov chain model with traditional direction and cooperative transmission strategies. Based on the previous description, we can derive the close forms for system performance metrics of saturation throughput and delay.

3.1. Throughput Analysis

Let S_i denote the normalized saturation throughput of a given priority i class [7]. We can express it as (20). The parameter E[$T_{P,i}$] is the average duration of transmitting payload information successfully in a slot time for the priority i class, which is derived as

$$\begin{aligned} S_i &= \frac{E\left[T_{P,i}\right]}{E\left[T_B\right]+\sum_{i=0}^{n-1} E\left[T_{S,i}\right]+E\left[T_{C,i}\right]+E\left[T_{E,i}\right]}. \\ E\left[T_{P,i}\right] &= P_{i,s}P_t\left[P_{i,r}\left(1-FER_{dir}\right)+\left(1-P_{i,r}\right)\left(1-FER_{i,coop}\right)\right]T_{payload}, \end{aligned} \tag{20}$$

where $T_{payload}$ is the average duration to transmit the payload information. The parameter $E[T_B]$ is the average duration of non-frozen backoff timer. And the parameters $E[T_{S,i}]$, $E[T_{C,i}]$ and $E[T_{E,i}]$ are the average duration for the priority i class of the successful transmission, the transmitted frame colliding and the transmitted frame is error due to the channel noise, respectively. Those parameters can be derived as

$$E\left[T_B\right]=\left(1-P_t\right)\sigma. \tag{21}$$

$$E\left[T_{S,i}\right]=P_{i,s}P_t\left[P_{i,r}\left(1-FER_{dir}\right)T_{i,dir}^{s}+\left(1-P_{i,r}\right)\left(1-FER_{coop}\right)T_{i,coop}^{s}\right]. \tag{22}$$

$$E\left[T_{C,i}\right]=P_{i,c}P_t\left[P_{i,r}T_{i,dir}^{c}+\left(1-P_{i,r}\right)T_{i,coop}^{c}\right]. \tag{23}$$

$$E\left[T_{E,i}\right]=P_{i,s}P_t\left[P_{i,r}FER_{dir}T_{i,dir}^{s}+\left(1-P_{i,r}\right)FER_{coop}T_{i,coop}^{s}\right]. \tag{24}$$

The parameters of above equations can be obtained as follows. σ is the size of a slot time. As mentioned before, FER_{dir} and FER_{coop} are the frame error rates at the destination via the traditional direction transmission and the cooperative transmission, respectively. $T_{i,dir}^{c}$ and $T_{i,coop}^{c}$ are the average durations for the priority i class that the channel is captured with a successful transmission via the traditional direction transmission and the cooperative transmission, respectively. Similarly, $T_{i,dir}^{c}$ and $T_{i,coop}^{c}$ are the average duration for the priority i class that the channel is captured with a collision. Note that the average time to detect the error frame is considered the same as that to receive the frame successfully. The values of the above durations depend on the channel access method and are defined as follows.

$$\begin{aligned}
T_{i,dir}^{s}&=T_{header}+T_{payload}+\delta+SIFS+T_{ACK}+\delta+AIFS[i],\\
T_{i,coop}^{s}&=2\left(T_{header}+T_{payload}+\delta+SIFS\right)+T_{ACK}+\delta+AIFS[i].\\
T_{i,dir}^{c}&=T_{header}+T_{payload}+\delta+AIFS[i],\\
T_{i,coop}^{c}&=2\left(T_{header}+T_{payload}+\delta\right)+AIFS[i].
\end{aligned} \tag{25}$$

RTS/CTS mechanism,

$$\begin{aligned}
T_{i,dir}^{s}&=T_{RTS}+\delta+SIFS+T_{CTS}+\delta+SIFS+T_{header}+T_{payload}+\delta+SIFS+T_{ACK}+\delta+AIFS[i],\\
T_{i,coop}^{s}&=T_{CRTS}+\delta+SIFS+T_{CTS}+\delta+SIFS+2\left(T_{header}+T_{payload}+\delta+SIFS\right)+T_{ACK}+\delta+AIFS[i].\\
T_{i,dir}^{c}&=T_{RTS}+\delta+AIFS[i],\\
T_{i,coop}^{c}&=T_{CRTS}+\delta+AIFS[i].
\end{aligned} \tag{26}$$

The parameters T_{header}, T_{ACK}, T_{RTS}, T_{CRTS} and T_{CTS} are the durations to transmit the header, ACK frame, RTS frame, CRTS frame and CTS frame, respectively. And δ is the propagation delay.

3.2. Delay Analysis

Saturation delay D_i is the average delay (defined as the time from the generation of a frame to the source is acknowledged by the destination) for the priority i class under the saturation condition and includes the interframe spaces (such as SIFS), the channel access delay (due to backoff, collisions, etc.) and the transmission delay [8]. Let X_i be the random variable representing the total number of backoff slots for the priority *i* class without considering the case that the backoff timer is stopped when the channel is sensed busy. The probability that the frame in the priority *i* class is successfully transmitted at the (*j*+1)th transmission and the average number of backoff slots that the station needs to transmit a frame successfully at the *j*th retry is $\sum_{h=0}^{j}\frac{W_{i,h}-1}{2}$. Thus, we have

$$E\left[X_i\right]=\left(\sum_{j=0}^{\ell}P_{i,dir}^{j}+\sum_{j=\ell+1}^{m+r}P_{i,dir}^{\ell}P_{i,coop}^{j-\ell}\right)\sum_{h=0}^{j}\frac{W_{i,h}-1}{2}P_{i,suce}, \tag{27}$$

where $P_{i,suce}$ is the probability for receiving correct frame at the destination for the priority *i* class which can be derived as

$$P_{i,suce}=P_{i,s}P_t\left[P_{i,r}\left(1-FER_{dir}\right)+\left(1-P_{i,r}\right)\left(1-FER_{coop}\right)\right]. \tag{28}$$

The probability that channel is sensed idle is (1–$P_{i,b}$). Let Fi be the random variable representing the total number of backoff slots when the backoff timer is stopped for the priority *i* class. Thus, we can regard E[X_i] and E[F_i] as the total number idle and busy slots that the frame encounters during backoff procedure , respectively. We have

$$E\left[F_i\right]=\frac{P_{i,b}}{1-P_{i,b}}E\left[X_i\right]. \tag{29}$$

Let E[BD_i] denote the average backoff delay that the station in the priority *i* class experiences before accessing the channel. We have

$$E\left[BD_i\right]=E\left[F_i\right]\left(P_{i,bs}T_{i,s}+P_{i,bc}T_{i,c}\right). \tag{30}$$

The parameters $P_{i,bs}$ and $P_{i,bc}$ are the probabilities that the transmission is successful and the transmitted frame collides on the condition that the channel is busy, respectively. We have

$$\begin{aligned}P_{i,bs}&=\frac{\left(N_i-1\right)\tau_i\left(1-\tau_i\right)^{N_i-2}}{P_{i,b}}\prod_{h=0,h\neq i}^{n-1}\left(1-\tau_h\right)^{N_h},\\P_{i,bc}&=1-P_{i,bs}.\end{aligned} \tag{31}$$

$T_{i,s}$ and $T_{i,c}$ are the total durations that the channel is captured with a successful transmission and a collision for the priority *i* class, respectively.

$$\begin{aligned}T_{i,s}&=P_{i,r}\left(1-FER_{dir}\right)T_{i,dir}^{s}+\left(1-P_{i,r}\right)\left(1-FER_{coop}\right)T_{i,coop}^{s},\\T_{i,c}&=P_{i,r}T_{i,dir}^{c}+\left(1-P_{i,r}\right)T_{i,coop}^{c}.\end{aligned} \tag{32}$$

Let E[$N_{i,retry}$] denote the average number of retries for the priority *i* class which is derived as

$$E\left[N_{i,retry}\right]=\left(\sum_{j=0}^{\ell}p_{i,dir}^{j}+\sum_{j=\ell+1}^{m+r}p_{i,dir}^{\ell}p_{coop}^{j-\ell}\right)P_{i,suce} \tag{33}$$

As mentioned before, the saturation delay includes the interframe spaces, the channel access delay and the transmission delay. Thus, the delay for the priority *i* class can be derived as

$$
\begin{aligned}
D_i &= E\left[X_i\right]\sigma + E\left[BD_i\right] + E\left[N_{i,retry}\right]\left(T_{i,c}+T_o\right)+T_{i,s} \\
&= E\left[X_i\right]\sigma + E\left[F_i\right]\left(P_{i,bs}T_{i,s}+P_{i,bc}T_{i,c}\right) + E\left[N_{i,retry}\right]\left(T_{i,c}+T_o\right)+T_{i,s}.
\end{aligned} \tag{34}
$$

T_o is the duration that a station has to wait when its frame transmission collides before sensing the channel again.

3.3. Cost Function Analysis

The optimal performance is achieving by maximizing the throughput and minimizing the delay. There is always a tradeoff between throughput and delay [9]. Thus, we introduce the concept of cost function C [10] that is the tradeoff between throughput and delay to determine the cooperative transmission strategy. The larger value of cost function means that the system performance is better because the throughput is higher and delay is smaller. The cost function is defined as the ratio of the saturation throughput (*S*) to the saturation delay (*D*), which can be derived as

$$
C = S/D. \tag{35}
$$

4. Numerical Results

In this section, we show the results that utilizing the optimal cooperative transmission strategy. The parameters of our analysis are as follows: Frame payload = 1023 bytes, ACK = 14 bytes, RTS = 20 bytes, CTS = 14 bytes, SIFS = 10 us, DIFS = 50 us, propagation delay = 1 us, CW_{min} = 32, CW_{max} = 1024. For demonstration purposes, we adopt four priority classes, i.e., i = 4. And we utilize the default parameter values which are defined in IEEE 802.11e standard.

The saturation throughput performances under different channel conditions are depicted in Fig. 2 to Fig. 3. From the results, we know that the IEEE 802.11e EDCA priority mechanism is quite effective in throughput. The contention window differentiation can provide the different probability of accessing the channel. A station with lower values of backoff parameters (CW_{min} and CW_{max}) has higher probability of winning the contention in comparison to station with higher values. Thus, AC_3 class has the highest priority because it has the lowest backoff parameters. The throughput of AC_0 is the same as AC_1 because the parameter $T_{Paylaod}$ of each AC is the same and the contention window parameters of AC_0 is the same as AC_1, i.e., the E[$T_{P,i}$] of AC_0 is the same as AC_1.

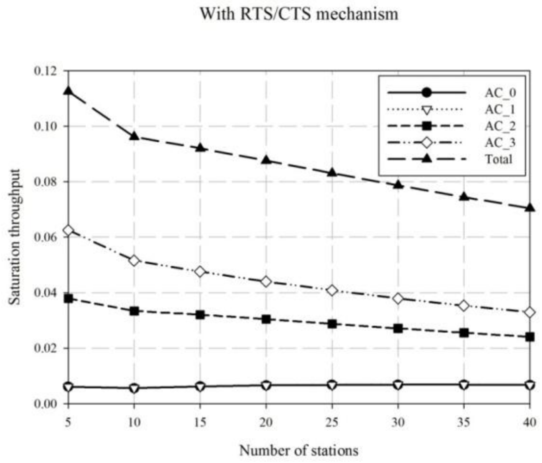

Fig. 2. Throughput with RTS/CTS mechanism (FERdir = 0.9)

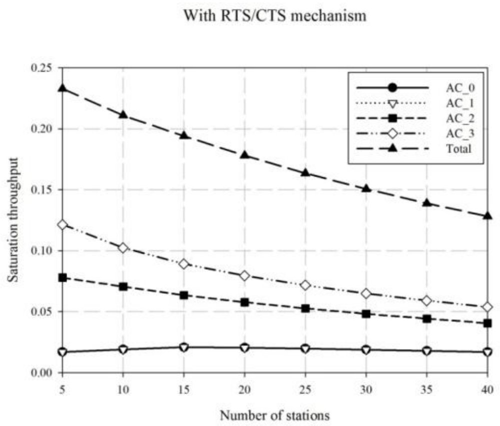

Fig. 3. Throughput with RTS/CTS mechanism (FER_{dir} = 0.6)

The delay performances under different channel conditions are depicted in Fig. 4 to Fig. 5. After every busy channel period, each station has to wait for the duration equal to its AIFS value. If the AIFS values are different, there is a time in which the stations with shorter AIFS values (the higher-priority) may access the channel, while the stations with longer AIFS values (lower-priority) are prevented from accessing the channel. Thus, the delay of AC_0 is higher than that of AC_1 because the value of AIFS[AC_0] is larger. The delay of AC_3 class is higher than that of AC_2 class because the parameter $P_{i,b}$ of the AC_3 class is much higher than that of AC_2 (about 1.6 times). Hence, the backoff delay (i.e., E[BD_i]) that the station in the priority AC_3 class experiences before accessing the channel is longer than the priority AC_2.

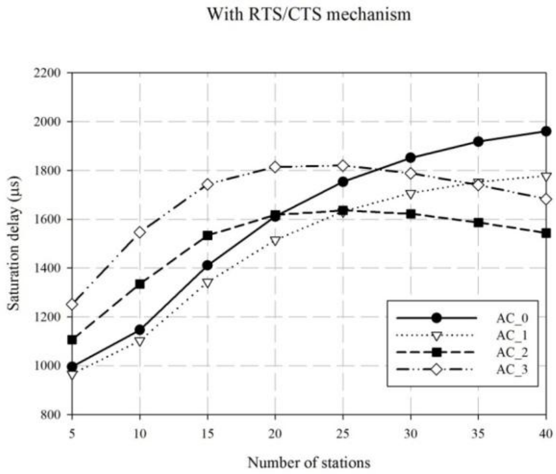

Fig. 4. Delay with RTS/CTS mechanism (FER_{dir} = 0.9)

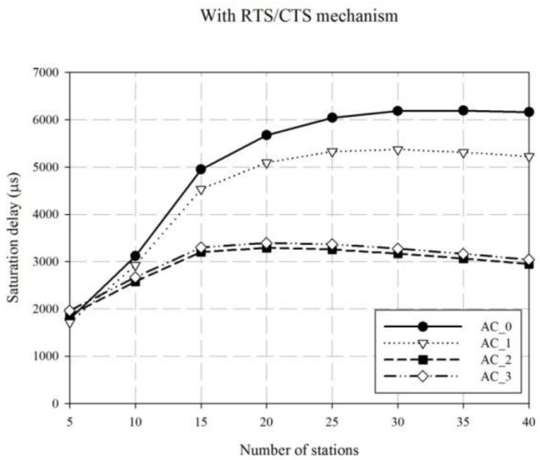

Fig. 5. Delay with RTS/CTS mechanism (FERdir = 0.6)

The cost function performances under different channel conditions are depicted in Fig. 6 to Fig. 7. We know that the EDCA mechanism provides the different priorities for differentiate services by using different backoff parameters and AIFS values. Thus, we can adjust the parameters to provide the different priorities with differentiated services to get better cost function.

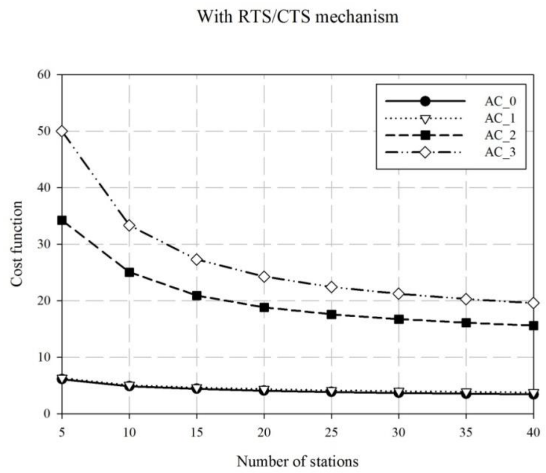

Fig. 6. Cost function with RTS/CTS mechanism (FER_{dir} = 0.9)

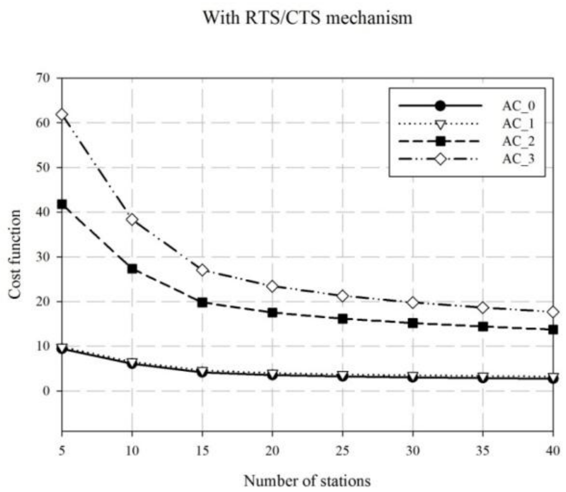

Fig. 7. Cost function with RTS/CTS mechanism (FER_{dir} = 0.6).

5. Conclusions

In this paper, the Markov chain model with traditional direction and cooperative transmission strategies is proposed to analyze saturation throughput and saturation delay. In general, cooperative communication can reduce the frame error rate; while the rerouting delay due to the additional signal transmitted from the relay to the destination can considerably degrade the system performance. To obtain optimal performance, the cost function is introduced to tradeoff the system performance to determine the strategy for adopting the cooperative transmission.

The theoretical analysis of this paper is very general, and we did not consider the multi-rate transmission for the QoS requirements. We can extend the model to support a multi-rate transmission and derive the numerical analysis in the future.

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