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Saturated Throughput Analysis of Enhanced Distributed Channel Access Mechanism for Supporting Multimedia Services

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Abstract

Enhanced Distributed Channel Access (EDCA) mechanism is used in WLAN to support QoS for various multimedia service flows. IEEE 802.11e EDCA introduces some new QoS parameters based on DCF. How to adjust these parameters is a significant problem. In the paper, we present a novel saturated throughput analysis of the IEEE 802.11e EDCA. This approach involves a novel analytical model that is an extension to previous works, which provide Markov chain analysis to IEEE 802.11e EDCA. Throughput analysis of our model is evaluated by comparison with NS2 simulations. We found the model is correct and suitable for both basic access and request-to-send/clear-to-send (RTS/CTS) access mechanisms.

Keywords: *modeling, performance evaluation, IEEE 802.11e EDCA, saturation, multimedia service flows*

1. Introduction

IEEE 802.11 wireless networks are utilized in a wide range of practical applications. Most wireless networks use IEEE 802.11 protocol. DCF based IEEE 802.11 protocol does not provide QoS support for the multimedia service flows. Due to the reason that IEEE 802.11e is able to support better QoS in WLAN. It has been included as mandatory part in the newest edition of IEEE 802.11 standard. There are two MAC protocols in IEEE 802.11e. One is called Enhanced Distributed Channel Access (EDCA) and the other one is called Hybrid Coordination Function Controlled Channel Access (HCCA). EDCA is designed for distributed networks while HCCA is for centralized networks. EDCA can be compatible with the DCF and is widely adopted to support QoS in WLAN. EDCA adds some new QoS parameters compared with DCF, which are also called EDCA parameters. The IEEE 802.11e standard only defines a suite of default values but how to adjust these EDCA parameters has not yet been mentioned. How to set up the EDCA parameters is the key point of QoS guarantee, which is important for supporting multimedia service flows and is worth investigating further.

2. The EDCA Analysis Model

The analysis model established in this paper is mainly manifested in: in allusion to prior distinction channel access features of IEEE 802.11e protocol which supports QoS, the paper presents a new performance analysis model method. Taken into consideration in saturation, the model analysis contains EDCA three main aspects: AIFS distinguish mechanism, channel

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and frame congestion mechanism and different contention window size. Under different transmission load, the number of nodes and network structure, the values of model analysis and simulation values are good agreement in the performance, such as the transmission throughout of each priority access, channel access delay and data loss rate.

For this model, assumptions are as follows: 1. Ideal channel ignoring capture effect. 2. Nodes have the same and fixed number of times of retransmission. The probability of each data frame collision does not depend on each other and is a constant. 3. The number of sites is fixed, and it does not take into consideration the hidden terminal problem.

2.1 Backoff Mechanism of EDCA

Using the proposed new three-dimensional discrete-time Markov chain model to analyze backoff mechanism of EDCA, in the Markov chain, a time slot is used to indicate a time interval between two consecutive backoff timer start, originally it is a parameter. However, for brevity, in this paper, in IEEE 802. 11b standard, it is assumed to be a fixed time interval. S(t) is to represent the backoff stage random process, b(t) is to represent a backoff timer for an access category (AC), and c(t)is to represent the number of remaining slots, which need to go through the time of a response inter-frame interval after through minimum arbitration inter-frame interval. The three-dimensional Markov process {s(t), b(t), c(t)} constitutes discrete-time three-dimensional process shown in Figure 1a, uses the dashed box to express the relationship of Markov subchain shown in Figure 1b.

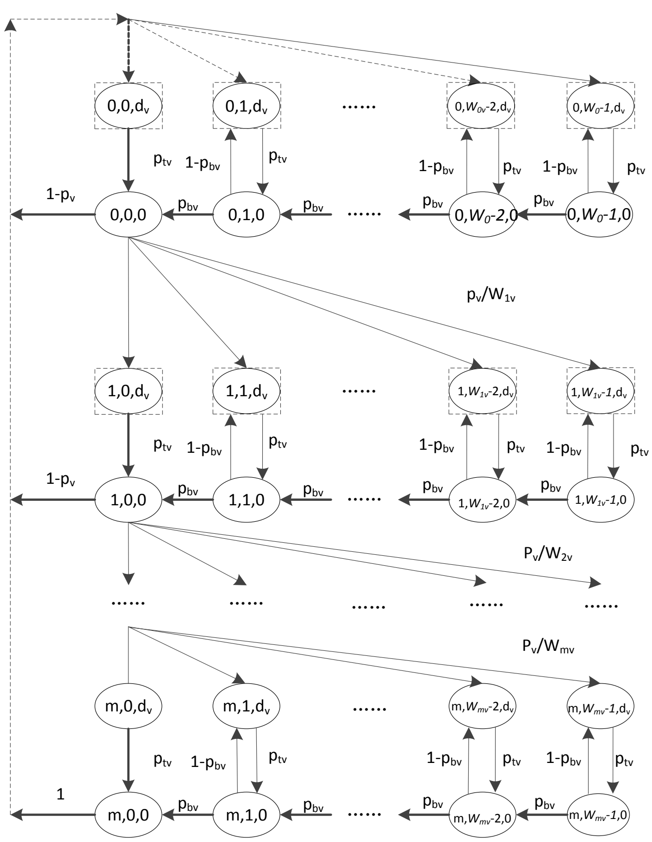

Figure 1a. Three-dimensional Markov Chain AC backoff Process Model

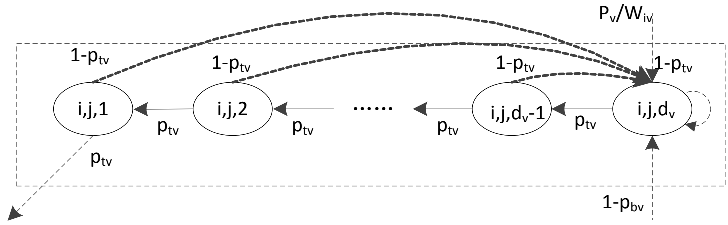

Figure 1b. Relationship of Markov Subchain

As shown in Figure 1, P_v expresses the probability that a node transmits a data frame occurring collision because of channel competition, P_{bv} expresses the probability that after access categories go through the inter-frame interval, the channel is still in an idle state in a time slot. P_{tv} expresses the probability that during the inter-frame interval which after access categories go through the minimum inter-frame interval. D_v expresses the difference of a time slot number in the time of a minimum inter-frame interval and inter-frame interval. $d_v=AIFSN_v\text{-}AIFSN_{min}\cdot m$ expresses retransmission limit. The analysis model reflects the state transition relation shown as follows:

$$\begin{cases} P\{i,j,0 \mid i,j+1,0\} = p_{bv}, & 0 \le i \le m, 0 \le j \le W_{iv}-2 & (1a) \\ P\{i,j,d_v \mid i,j,0\} = 1-p_{bv}, & 0 \le i \le m, 1 \le j \le W_{iv}-1 & (1b) \\ P\{i,j,0 \mid i,j,1\} = p_{tv}, & 0 \le i \le m, 0 \le j \le W_{iv}-1 & (1c) \\ P\{i,j,k \mid i,j,k+1\} = p_{tv}, & 1 \le k \le d_v-1 & (1d) \\ P\{i,j,d_v \mid i,j,k\} = 1-p_{tv}, & 1 \le k \le d_v & (1e) \\ P\{i,j,d_v \mid i-1,0,0\} = p_v / W_{iv}, & 1 \le i \le m, 0 \le j \le W_{iv}-1 & (1f) \\ P\{0,j,d_v \mid i,0,0\} = (1-p_v)/W_{0v}, & 0 \le i \le m-1, 0 \le j \le W_{iv}-1 & (1g) \\ P\{0,j,d_v \mid m,0,0\} = 1/W_{0v}, & 0 \le j \le W_{iv}-1 & (1h) \end{cases}$$

W_{iv} expresses the contention window of non-successful transmission i times. W_{iv} can be expressed as:

$$W_{iv} = \begin{cases} 2^i W_{0v} & 0 \le i < m' \\ 2^{m'} W_{0v} & m' \le i \le m \end{cases} \qquad (2)$$

where W_{0v} and $2^m W_{0v}$ respectively expresses ACv corresponding to CW_{min} and CW_{max}.

The probability relation of state transition equation (1a) to (1h) is expressed successively as follows: A. Whenever through an idle time slot, the backoff timer minus one. B. While scouting the channel in a busy state, the backoff process will be in a frozen state. C. The backoff timer will be recalled after passing inter-frame interval. D. If the channel is scouted in an idle state in a time slot, the remaining time-slot number which is in the inter-frame gap time will minus one. E. When the channel is scouted in a busy state in the inter-frame gap time, access category has to pass an inter-frame gap time again. F. The node is in a suspended state when the backoff timer reduces to zero, then wait for the corresponding inter slot to perform a transmission. If the data frame transmitted in the channel has error, the node contention window value will be updated and then enter the next backoff process immediately.

G. After a successful transmission, CW is set $CW_{min.}$ H. The number of retransmission reaches to the highest times limit, the CW value is set $CW_{min.}$

The probability $b_{i,j,k}$ of the Markov chain state{i, j, k} satisfies the following relation:

$$1=\sum_{i=0}^{m}\sum_{j=0}^{w_{iv}-1}b_{i,j,0}+\sum_{i=0}^{m}\sum_{j=0}^{w_{iv}-1}\sum_{k=1}^{d_v}b_{i,j,k} \qquad (3)$$

where, $i\in[0,m], j\in[0,W_{iv}-1], k\in[0,d_v]$

Calculating the three-dimensional Markov chain state equation can get the initial state of $b_{0,0,0}$,

$$b_{0,0,0}=[\frac{(1-p_{tv}^{dv})}{(1-p_{tv})p_{tv}^{dv}}((1-p_{bv})\sum_{i=0}^{m}\frac{W_{iv}-1}{2}p_v^i+\frac{1-p_v^{m+1}}{1-p_v})+\sum_{i=0}^{m}\frac{W_{iv}-1}{2}p_v^i+\frac{1-p_v^{m+1}}{1-p_v}]^{-1} \qquad (4)$$

When AIFS of access category is at a minimum, d_v can consider equal to zero, therefore, the above expression can be written as:

$$b_{0,0,0}=[\sum_{i=0}^{m}\frac{W_{iv}-1}{2}p_v^i+\frac{1-p_v^{m+1}}{1-p_v}]^{-1} \qquad (5)$$

In view of the saturation condition, namely that the transmission queue is non empty. The probability that access category AC*v* transmits successfully in a time slot randomly selected can be expressed as:

$$\tau_v=\sum_{i=0}^{m}b_{i,0,0}=b_{0,0,0}\sum_{i=0}^{m}p_v^i=\frac{b_{0,0,0}(1-p_v^{m+1})}{1-p_v} \qquad (6)$$

2.2 The Relevant Parameter of EDCA

IEEE 802.11e protocol is designed to improve the QoS that supports multimedia service flows.

The protocol stipulates that access category audio (AC3), video (AC2), best effort (AC1) and background (AC0) by the priority from low to high, and they also have a corresponding queue. When the media channel is being idle, the time that different queues need to wait for depends on AIFS, queue which has high priority has smaller contention window value and also has smaller created resignation process time, so the probability of that high priority business competes to get the channel is higher. The relationship expression between AIFS time value and the parameter AIFSNi is $AIFS_i=SIFS+AIFSN_i\cdot T_e$, which the unit time slot is $T_{e.}$

Assuming that the probability of access category ACi successful transmission is p_i. If each access category ACi has the same number of nodes n_i, that when a node is successfully competing to get the channel and transmitting unmistakably within the appointed time, it belongs to successful transmission. The probability p_{si} of ACi successful transmission reaches a conclusion by analyzing the literature [1]:

$$p_{si}=n_i\tau_i(1-\tau_i)^{n_i-1}\prod_{\substack{j=0\\j\neq i}}^{3}(1-\tau_j)^{n_j} \qquad (7)$$

If we want to know all the probability of AC successful transmission, first of all, we can know the probability p_s of AC successful transmission in an appointed time slot,

$$p_s=\sum_{i=0}^{3}p_{si} \qquad (8)$$

In the process of wireless LAN transmission, if the transmission channel is busy in a time slot, the probability is the same as the probability that at least one node transmits data packets in the channel. The expression of the probability p_B is:

$$p_B = 1 - \prod_{i=0}^{3} (1-\tau_i)^{n_i} \tag{9}$$

When the channel is busy, the node scouts that at least one node is transmitting data packets in the media channel; assuming the probability is p_{Bi}, and we can consider that the probability p_{Ci} of the data frame collision is equal to p_{Bi}, and the relevant probability formula[1] is:

$$p_{Bi} = p_{Ci} = p_i = 1-(1-\tau_i)^{n_i-1} \prod_{j=0,\, j\neq i}^{3} (1-\tau_j)^{n_j} \tag{10}$$

2.3 Analysis of Throughput

Throughput of access category AC*i* is equal to the data packet size of the access category successful transmission in the unit competition time. According to the analysis of the literature [1], we can get the throughput of the average per node S_i, it can be expressed as:

$$S_i = \frac{p_{si} T_{DATA}}{n_i T_{CS}} \tag{11}$$

where the duration of the competition T_{CS} can be expressed as:

$$T_{CS} = (1-p_B)T_e + p_s T_s + (p_B - p_s)T_c \tag{12}$$

Which, T_e is the unit time slot, δ is the transmission delay, T_s is on behalf of the time of successful transmission, T_c is on behalf of the time of collision. According to the derivation of the literature[1], under the basic transmission access visitor mode, the relationship between T_s and T_c is:

$$T_s = \min[AIFS_i] + T_H + T_{DATA} + SIFS + ACK + 2\delta \tag{13}$$

$$T_c = T_H + T_{DATA} + \delta + EIFS_{\min} \tag{14}$$

where T_H is the total transmission time of PHY header and MAC header in the data header file. $AIFS_{min}$ is the minimum arbitration inter-frame interval value in the AC access category. The minimum value of an extended inter-frame interval *EIFS* is $EIFS_{min}$. $AIFS_{min}$ and $EIFS_{min}$ can be expressed as:

$$EIFS_{\min} = SIFS + ACK + AIFS_{\min} \tag{15}$$

$$AIFS_{\min} = SIFS + ACK + AIFSN_i \cdot T_e \tag{16}$$

Under the RTS/CTS transmission access visitor mode, the relation of T_s and T_c is:

$$T_s = RTS + CTS + \min[AIFS_i] + T_H + T_{DATA} + SIFS + ACK + 4\delta \tag{17}$$

$$T_c = RTS + EIFS_{\min} \tag{18}$$

Then depending on the above several expressions we can calculate the probability of successful transmission and calculate the corresponding throughput of AC.

3. The Simulation Analysis of IEEE 802.11e EDCA

3.1 The Topology of IEEE 802.11 Network

In the IEEE 802.11 network, there are primarily two kinds of topological structure, that is, basic network and special network.

3.2 Basic Network

Figure 2 is the network structure of Infrastructure Basic Service Set. In the basic network, in fact is the standard infrastructure mode, this structure is based on the wireless access point (AP) as the control center. The access point provides basic transmission service to the all STA nodes. It cannot communicate directly between STA nodes, that is, in order to ensure the whole network normally communicating, we must continuously ensure the wireless access point normally working. This is a weakness in the network.

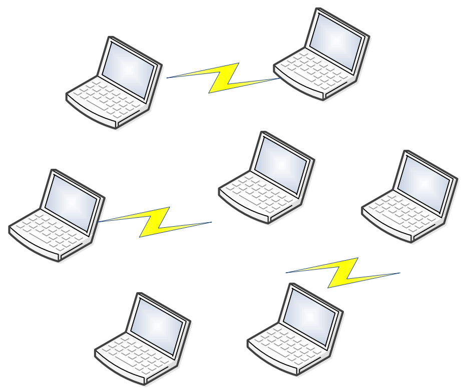

Figure 2. Basic Network

3.3 Independent Network

Figure 3 is the Independent Basic Service Set, known as IBSS. Unlike basic service set, it is the standard Ad hoc network which does not have a central access point. It is peer to peer relationship between sites, also called peer to peer network.

In Ad hoc mode, in the practical application, it can achieve customers' centralized and unified management, meet the needs of customers and support flexible marketing strategy. Technically, it achieves flexible customization on the management of service.

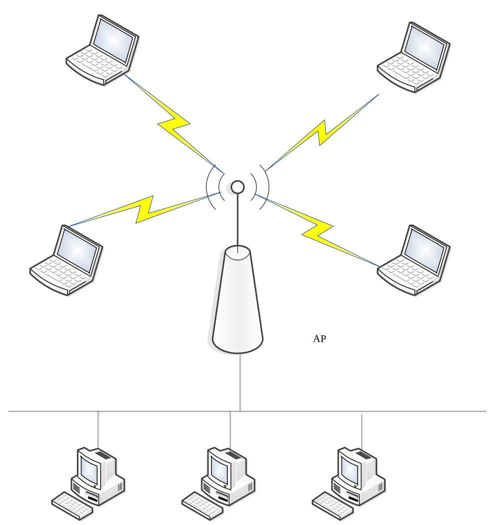

Figure 3. Independent Network

3.4 Extended Network

Extended service set is a distributed system consisting of several basic service sets, shown in Figure 4, all the STA sites can communicate directly with each other. It can be equivalent to a peer to peer network (Ad hoc) in the logical link control (LLC) layer. The node moves in the range of ESS, and the node is not visible in logic in the higher protocol layer. Multiple BSS and DS can form a wireless network which can cover a wide range. It is called extended service set network [2] in the IEEE 802.11b protocol.

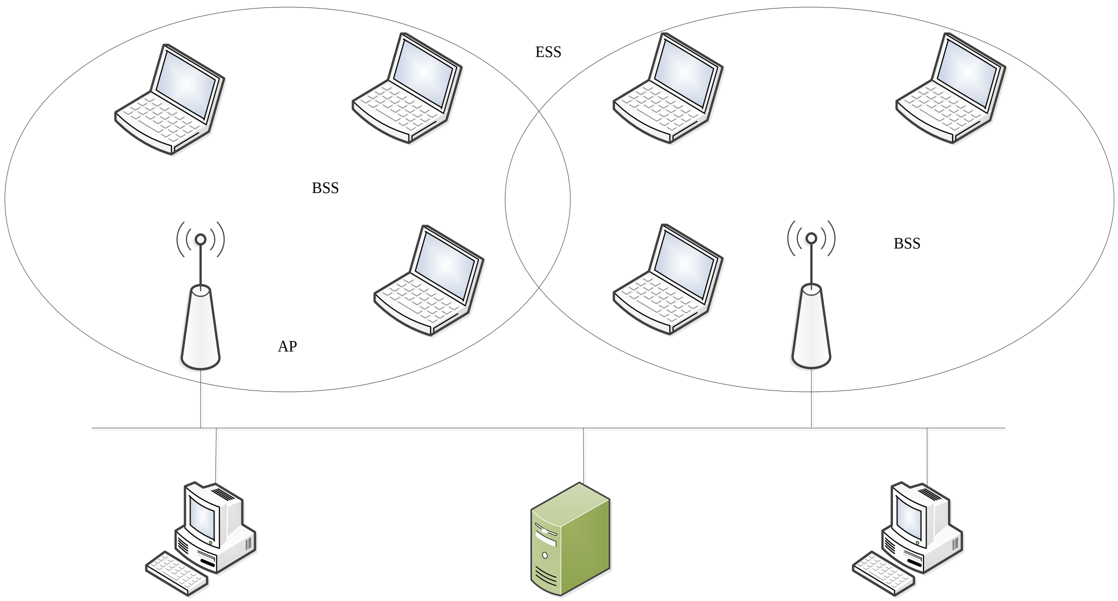

Figure 4. Extended Network

Due to the ambiguity of the wireless network, not every network node can communicate directly with other nodes. There are three important parameters for a wireless network node: the transmission range (R_t), the physical carrier sensing range (R_{CS}), the interference range (R_{IF}). This paper only considers the transmission range and the physical carrier sensing range. For example, there are wireless network nodes A, B, C, assuming that while A is transmitting data to B, C also transmits data to B. But because A is far from C, they cannot receive information from each other, namely that A does not detect the existence of C. For A, C is the hidden node.

With the existence of the hidden node, when two nodes, A and C send data packet to B at the same time, there will happen collision in B leading to occur an error while receiving the data frame, resulting the waste of bandwidth.

3.5 The Selection of Network Topology

Establishing and analyzing our model, then the results of the simulation software NS2 are compared with the theoretic results by analyzing the model. The two assumed conditions of using NS2 simulation tool is: 1. The access point and all the other nodes have the name transmission range. 2. All the antennas are unidirectional. So, the range of transmission and carrier sense is a circle which the radius is constant. In this paper, we use the annular topological structure.

3.6 The Network Scenario of The Annular Topological Structure

Due to the hidden effect, minimize the impact of the capture effect, the annular topological structure is a good choice. Because it has a wireless access point in the center, the other nodes around the center to form a circle distributing on the circumference regularly. This topology has the following benefits:

Other nodes have the same distance from the wireless access point center, so the capture effect can be neglected. Secondly, the topological structure is symmetrical to the wireless access point center. So, each node has the same throughput.

The another benefit is that we can easily change and control the radius of the circle where the hidden node is there, from the carrier sensing range of each node can know the number of overlay nodes and hidden nodes, the transmission range (R_T) and the physical carrier sensing range (R_{CS}) are set to 250 meters. In this study, we change the radius value, denoted as R, such as setting the scene 1, we can obtain different hidden nodes' conditions in a system which consists of 8 nodes. The value of R is set to four:

A. R=120m, each node can scout all the data packets sent from other 7 nodes.

B. R=130m, only one node is the hidden node. The other 7 nodes are the overlay node.

C. R=155m, there are three hidden nodes and 4 overlay nodes.

D. R=180m, the number of the hidden node reaches 5. The overlay node only has 2.

Similarly available we can set the network scene topology 2, make 16 nodes distribute on the circumference regularly that the access point is the center. The transmission range (R_T) and the physical carrier sensing range (R_{CS}) are set 597 meters. In this structure, the radius is R. Separately taking four different values of 270 meters, 300 meters, 315 meters and 340 meters. The hidden node number corresponded is 0, 1, 3, 5[2].

For the network simulation scene, we can correspondingly set as follows: use the same annular topological structure, but set the reasonable value of R. In this paper set it 100 meters, and all the systems do not produce the hidden terminal effect. Separately set the network system of 2, 4, 6, 8, 10, 12, 14, 16 nodes and test and verify the throughput of the basic access visit and the RTS/CTS access visit, combined with analysis value of the IEEE 802.11e model.

The parameters used in network simulation are listed in Table 1, set up two scenes, scene 3 and scene 4. Scene 3 only considers AC2 and AC3, can be seen in Table1 the parameters set up. Such setting is for obtaining the effects of different contention window size for each access category throughput in the same AIFS condition. Similarly available in the scene 4, we can obtain the effects of different AIFS for each access category throughput in the same contention window size. Assuming the number of nodes of each access category is also the case, and considering the node number is 2, 4, 6, 8, 10, 12, 14 and 16 eight cases. To study the relationship between the number of nodes and the throughput of each access category per node, comparative mapping analysis is shown in Figure 5 and Figure 6.

From Figure 5, we can see that the results of simulation are fit well with the analysis of the model. Data flow of the smaller contention window usually has higher volume of business. With the number of nodes increasing in each access category, the volume of business will reduce. This is because the number of nodes too much will lead to channeling more competitive. From Figure 6 can be seen that AC1 and AC0 have the same contention window size. Compared with AIFS smaller, AC1 has higher volume of business. Similarly, with the number of nodes of each access category increasing, the volume of business will reduce, and it also will appear AC0 background flow shortage.

Table 1. Parameter Settings of EDCA

Transmission Rate	1 Mbps
Packet Payload	1000 Bytes
MAC header	224 bits
PHY header	192 bits
RTS	160 bits + PHY header
CTS	112 bits + PHY header
ACK	112 bits + PHY header
DIFS	50 μs
SIFS	10 μs
Slot Time (T_e)	20 μs
Propagation Delay (δ)	1μs
Basic Rate	1Mbps
Retransmission limit	7
AIFSN	$AIFSN_0$=7,$AIFSN_1$=3, $AIFSN_2$=2, $AIFSN_3$=2
CW[voice]	CW_{min} = 7, CW_{max} = 15
CW[video]	CW_{min} = 15, CW_{max} = 31
CW[best effort]	CW_{min} = 15, CW_{max} = 1023
CW[background]	CW_{min} = 15, CW_{max} = 1023

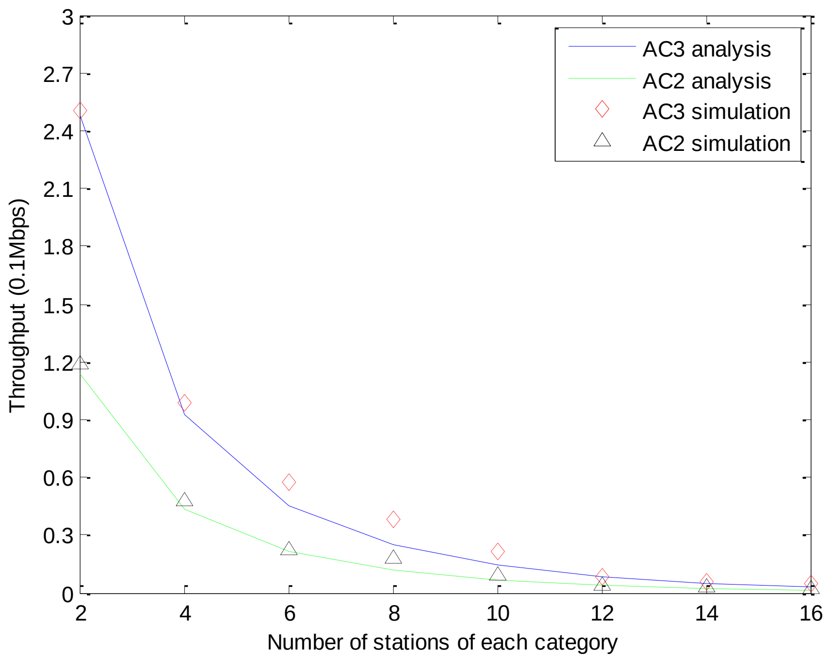

Figure 5. The Relationship of Analysis Value and Simulation of Audio and Video

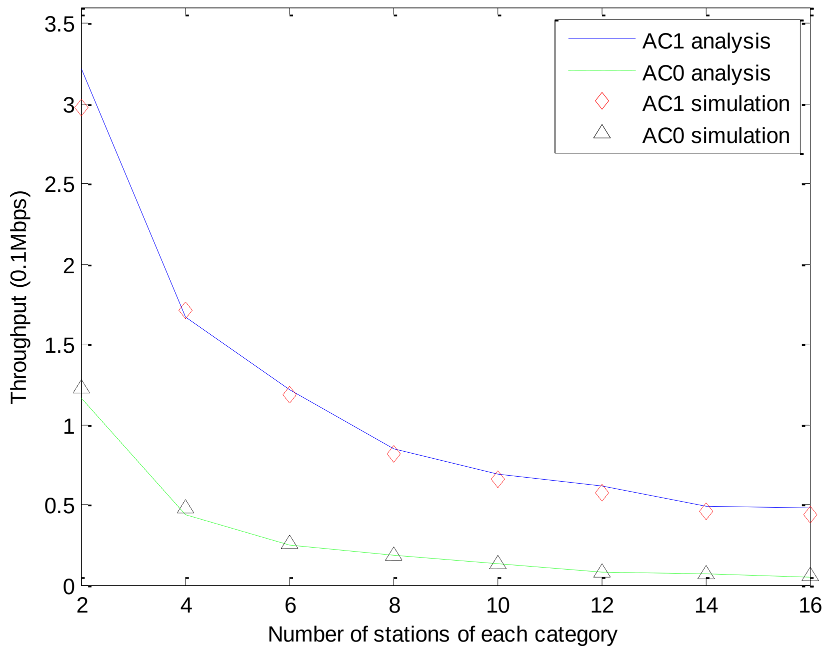

Figure 6. The Relationship of Analysis and Simulation Value of Best Effort and Background

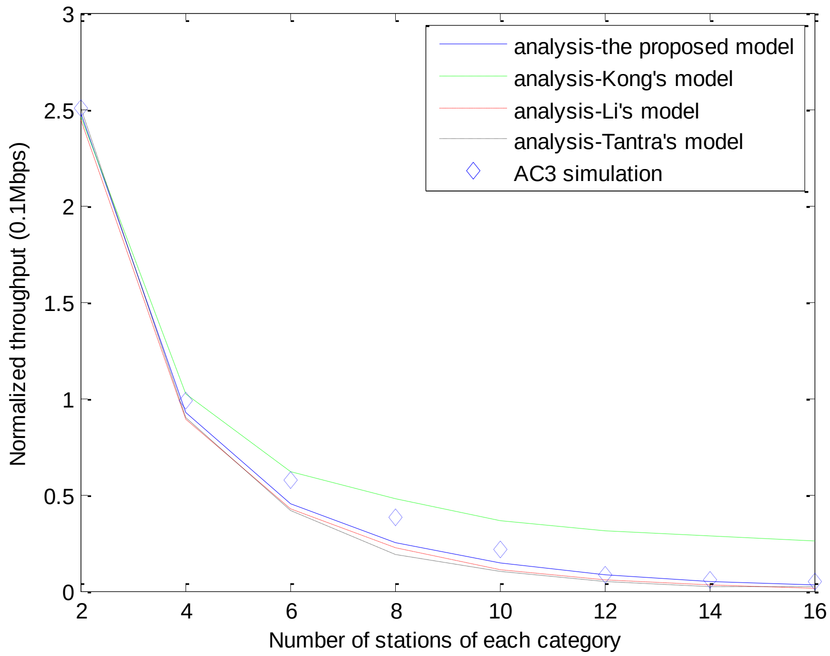

Figure 7. Contrast of Analysis and Simulation Value of Audio in Four Models

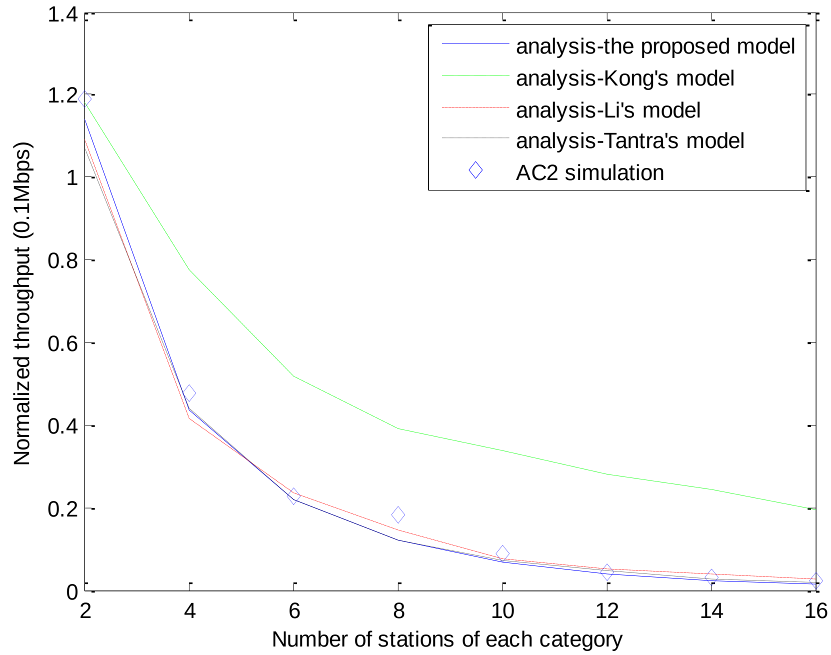

Figure 8. Contrast of Analysis and Simulation Value of Video in Four Models

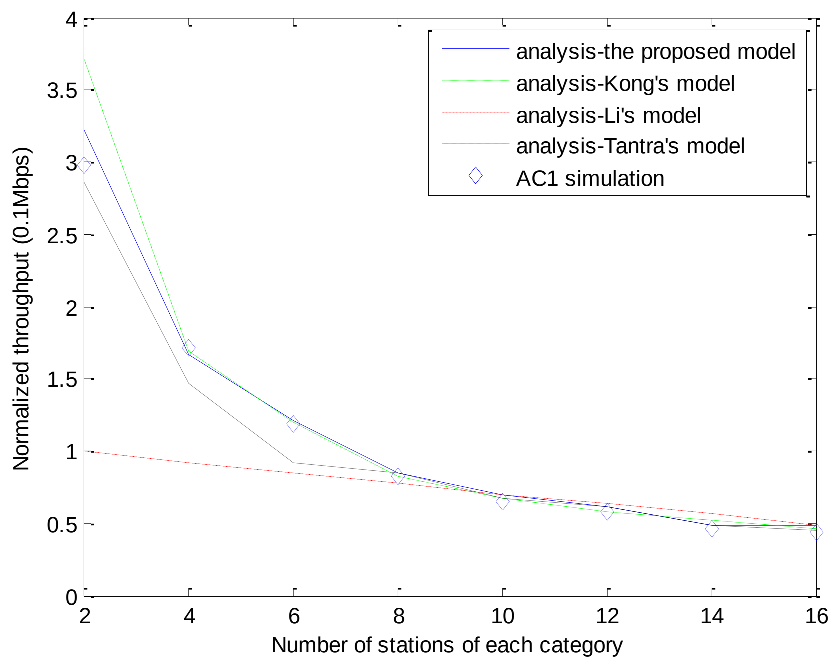

Figure 9. Contrast of Analysis and Simulation Value of Best Effort in Four Models

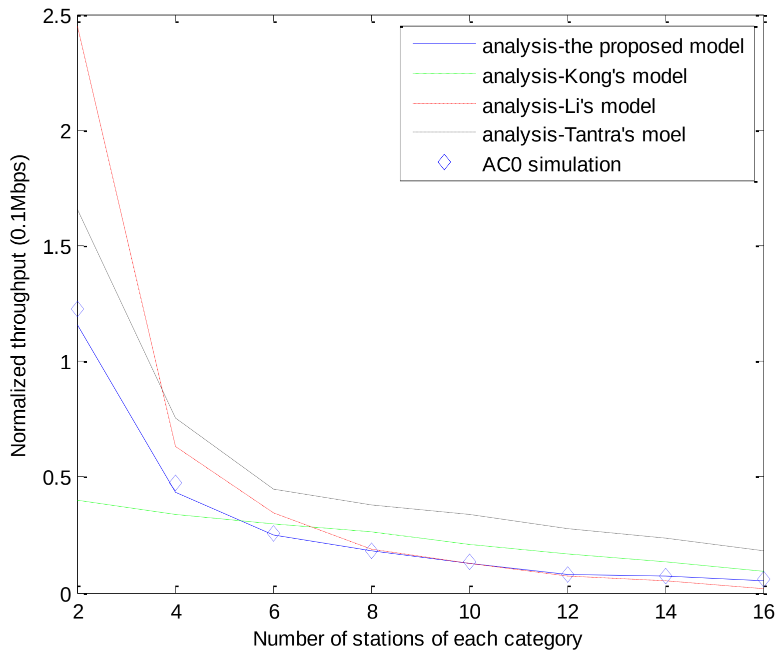

Figure 10. Contrast of Analysis and Simulation Value of Background in Four Models

From Figure 5 and Figure 6 comprehensive comparisons, AIFS and the contention window size will affect the volume of the business. Different AIFS affects the probability of transmission in the competition area. Low priorities nodes will be excluded from the competition area and let high priority business have higher transmission probability and broadband resources. However, different window size for low priority nodes can produce long delay. Low priority nodes still have a chance to transmit. When AC3 audio and AC2 video nodes increasing, the volume of business of access category will be reduced. AIFS and contention window of audio and video are small. This makes the node transmission probability higher in the unit time slot. This will make the collision probability increasing. So when the number of nodes becomes large, main broadband resources will be consumed by node collision. The each result of four access categories AC3, AC2, AC1, AC0 successively compares with the model of Kong [3], Li [4] and Tantra [5]. Contrast the throughput business of each simulation access category with the analysis of four models comprehensively. Figure 7, Figure 8, Figure 9 and Figure 10 separately express the throughput of AC3, AC2, AC1, AC0. On the whole, the throughput of AC access category which the analysis model of this paper describes is more in line with the throughput business of Kong, Li and Tantra model. This shows that the analysis model of the paper is able to reflect the features of priority classification and two levels of conflict [6, 7] in IEEE 802.11e protocol more accurately.

4. Conclusion

In this paper, we present a novel saturated throughput analysis of the IEEE 802.11e EDCA. This approach involves a novel analytical model that is an extension to previous works by other authors, which provide Markov chain analysis to IEEE 802.11e EDCA. Throughput analysis of our model is evaluated by comparison with NS2 simulations and found the model is accurate and suitable for both basic access and request-to-send/clear-to-send (RTS/CTS) access mechanisms.

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