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Table of Contents

Table of Contents

Front Matter

1: Plenary Session: Best Paper Candidates

2A: Content-Centric Networking

2B: Realtime and Multimedia Communications

2C: SDN and Data Centers

Poster Session 1

3A: Performance Evaluation

3B: Internet of Things

3C: Security and Privacy

4A: Mobility and Location Dependent Services

4B: Security

4C - Ad Hoc, Sensor and Mobile Networks

Poster Session 2

5A: Cloud Computing

5B: Network Devices and Services

LCN W

Table of Contents

Table of Contents

Front Matter

Twelfth IEEE International Workshop on Practical Issues in Building Sensor Network Applications (IEEE SenseApp 2017)

Session 1: Energy-Efficient Operation of Wireless Sensor Networks

Session 2: Practical Experiences from Sensor Network Deployments

The International Workshop on Enabling Communications and Networking for Future Internet (WECNet'17)

11th Workshop on User MObility and VEhicular Networks (ON-MOVE 2017)

OnMove Session 1

OnMove Session 2

The 2nd IEEE International Workshop on Networks of Sensors, Wearable, and Medical Devices (NSWMD)

NSWMD Paper Session 1

IEEE International Workshop on 5G in Internet of Things (5G-IoT)

5G-IoT Paper Session 1

5G-IoT Paper Session 2

LCN Workshops 2017 Author Index

IEEE WECNet 2017 Conference »Program

The first IEEE International Workshop on Enabling Communications and Networking for Future Internet 2017 Program

⚠ WS-WN1: The last paper presentation ends before (09:30) the session end time of 10:30.

⚠ WS-WN2: The last paper presentation extends beyond (13:00) the session end time of 12:30.

⚠ WS-WN3: The last paper presentation extends beyond (16:00) the session end time of 15:00.

Time	Robertson
Monday, October 9	
09:00-10:30	*WECNET: Keynote and Paper session 1*
11:00-12:30	*WECNET: Paper session 2*
13:30-15:00	*WECNET: Paper session 3*

Monday, October 9, 09:00 - 10:30

WECNET: Keynote and Paper session 1

Challenges of IoT - the expected and the unforeseen
Damla Turgut

Room: Robertson

The internet of things refers to collection of internet connected computational devices embedded into the objects of the physical world. It is expected that some of these devices perform sensing and actuation functionality. Visions of the internet of things often refer to a world were many (or all) the physical objects we interact with are part of the internet of things. In recent years the IoT paradigm had experienced significant hype, but also faced some stinging criticisms outlining challenges to its implementation. Some of these challenges were known and expected. Other ones are the type that would have been difficult to foresee ten years ago. Yet another ones are the kind which we could have definitely foresee, but we did not. For instance, we were relatively good at predicting the technical challenges associated with the IoT. The security and privacy issues were known and expected, yet certain attacks against IoT systems took us by surprise. At this moment it is clear that the business cases and economic models associated with different IoT applications were not clearly thought through. And essentially nobody anticipated "day two" issues - how are we going to operate, maintain and update an IoT environment once it is deployed? In this talk we discuss some challenges faced by the IoT world in 2017, identify research objectives and try to draw some lessons from them.

An Algorithm for Alleviating the Effect of Hotspot on Throughput in Wireless Sensor Network
Abdul Rehman, Sadia Din and Anand Paul (Kyungpook National University, Korea); Waqar Ahmad (National Textile University, Pakistan)

Monday, October 9, 11:00 - 12:30

WECNET: Paper session 2

Room: Robertson
Chair: Sohail Jabbar (Kyungpook National University, South Korea & National Textile University, Faisalabad, Pakistan)

Enabling Smart Querying on Mobile Sensor's Data Using Semantical Annotation
Sohail Jabbar (Kyungpook National University, South Korea & National Textile University, Faisalabad, Pakistan); Kaleem Malik (COMSATS Institute of Information Technology Sahiwal, Pakistan); Muhammad Farhan (COMSATS Institute of Information Technology, Pakistan); Muhammad Imran (King Saud University, Saudi Arabia)

Internet of Things Based Architecture for Smart Community Design and Planning Using Big Data Analytics
Muhammad Babar (National University of Sciences and Technology, Islamabad, Pakistan); Fahim Arif (National University of Science and Technology, Pakistan)

SDIoT: Software Defined Internet of Thing to Analyze Big Data in Smart Cities
Sadia Din (Kyungpook National University, Korea); Awais Ahmad (Yeungnam University, Korea); Muhammad Mazhar Ullah Rathore (Kyungpook National University, Buk-gu, Deagu, South Korea, Korea); Anand Paul (Kyungpook National University, Korea); Murad Khan (Sarhad University of Science and Technology, Pakistan)

BGP Route Leak Prevention Based on BGPsec
Jia Jia (China Internet Network Information Center); Zhiwei Yan (CNNIC, P.R. China); Guanggang Geng (China Internet Network Information Center, P.R. China); Hongtao Li (CNNIC, P.R. China); Syed Hassan Ahmed (University of Central Florida, USA); Baoping Yan (Computer Network Information Center, P.R. China)

Monday, October 9, 13:30 - 15:00

WECNET: Paper session 3

Room: Robertson

Vehicular Speed Learning in the Future Smart-cities' Paradigm
Fadi M. Al-Turjman (Middle East Technical University, NCC, Turkey)

A Distributed Energy-Aware Cooperative Multimedia Delivery Solution
John Monks and Gabriel-Miro Muntean (Dublin City University, Ireland)

Enhancements in Data-Recovery and Re-Transmit Mechanisms of Transmission Control Protocol Enabled Medical Devices
Junaid Chaudhry (Edith Cowan University, Australia); Mudassar Ahmad, Muhammad Asif Habib and Rehan Ashraf (National Textile University, Pakistan); Craig Valli (Edith Cowan University, Australia)

Energy Aware Smart Home Management System Using Internet of Things
Sarah Kaleem (Iqra National University, Peshawar, Pakistan); Muhammad Babar (National University of Sciences and Technology, Islamabad, Pakistan); Murad Khan (Sarhad University of Sciences and Information Technology, Peshawar, Pakistan)

I-DTMC: An Integrated-Discrete Time Markov Chain Model for Performance Analysis in Future WLANs
Rashid Ali (WIN LAB., Yeungnam University & WINLab, Korea); Yousaf Bin Zikria and Farhan Amin (Yeungnam University, Korea); Byung-Seo Kim (Hongik University, Korea); Sung Won Kim (Yeungnam University, Korea)

2017 IEEE 42nd Conference on Local Computer Networks Workshops

I-DTMC: An Integrated-Discrete Time Markov Chain Model for Performance Analysis in Future WLANs

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***Abstract*—The IEEE 802.11 MAC protocol uses Distributed Coordinated Function (DCF) as the main element to determine the efficiency in sharing the limited resources of the wireless channels in wireless local area networks (WLANs). For analyzing 802.11 DCF networks, one of the key assumptions commonly used is that every station always has a packet to transmit (saturated state). However, in practice it may not be valid. In this paper, we assess the accuracy of the non-saturated traffic condition by integrating the traditional M/G/1 queueing model into Discrete Time Markov Chain (DTMC) model. The proposed I-DTMC enables us to analyze the performance of per-station in terms of average MAC system delay observed by each packet for successful transmission over the medium. The comparative results show enhanced performance evaluation of 802.11 DCF against other models.**

***Index Terms*— IEEE 802.11 DCF; analytical models; future WLANs; medium access mechanisms; DTMC model.**

I. INTRODUCTION

Efficient medium allocation in the MAC layer is one of the important target areas for future WLAN researchers. Distributed Coordination Function (DCF) is the primary resource allocation mechanism of IEEE 802.11. The DCF is a random access mechanism and is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol [1]. Bianchi [2] [3] is known as one of the pioneer to present a two dimensional Discrete Time Markov Chain (DTMC) model to obtain the maximum throughput under the assumptions of ideal channel with only collision probability and saturated traffic condition. However, in practice these assumptions may not be valid, particularly under the performance analysis of per-STA's non-saturated traffic condition. Although, some of the research works [4-6] have already investigated the non-saturated traffic conditions in the WLANs, yet these models lack of either busy channel probability (freezing state) due to start of transmission during the back-off counter (BC), or idle state (decrement state) of the tagged STA. In this paper, we redefine these limitations of Weng et. al. [4] and Xu et. al. [5]. The Weng et. al. [4] tried to redefine the definitions of busy state probability and the probability to retransmit after completing the total number of stages used in [7]. The Weng's model improves Ziouva's model [7] and gives more accurate analyses of the DCF, however their definition of proposed model has limitation of joining first stage of the back-off process after the packet arrives for contention (section II describes contention process in detail). In their proposed model, they assume probability of joining first stage of the DTMC similar as of collision probability during transmission, which makes the collision resolution analysis less efficient as compared to the actual DCF procedure. Similarly, Xu et. al. [5], assumes back-off freezing probability as constant (equal to one) due to the busy channel state. However, an STA might suffer from back-off freezing state during the back-off procedure if any of the other STA starts transmitting before it finishes the BC.

In this paper we perform an ample analysis, focusing on modeling the performance of DCF-based per-STA which accounts for the effects of non-saturated traffic condition on the collision rates and the average MAC system time of the packets of a single STA in network by overcoming these limitations. The proposed model provides an artifact combination of DTMC model for 802.11 DCF in non-saturated traffic condition and an M/G/1 queueing model; we named it as Integrated-DTMC (I-DTMC). This improved and integrated characterization allows a simpler and accurate model for the service time distribution of the STAs to be analyzed.

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The remainder of the paper is organized as follows. Section II defines the collision resolution process of IEEE 802.11 DCF in details. The proposed analytical model of I-DTMC for future WLANs is described in Section III. In Section IV, we determine the average MAC system time for each STA. The Section V validates our proposed model by numerical results comparing with Weng's and Xu's models. A comprehensive conclusion is presented in Section VI.

II. IEEE 802.11 DCF COLLISION RESOLUTION

The IEEE 802.11 MAC layer is responsible for resource allocation and is implemented using a DCF function based on CSMA/CA protocol [1]. The CSMA/CA IEEE 802.11 DCF protocol is designed to reduce the collisions due to multiple STAs transmitting simultaneously on the shared resources. In a network using, the 802.11 DCF protocols, each STA with a packet to transmit first senses the medium to discover whether it is in use. If the medium is sensed to be idle for an interval greater than the Distributed Inter-Frame Space (DIFS) interval, the STA proceeds with its transmission. If the medium is sensed as busy, the STA defers transmission till the end of the ongoing transmission. The STA then initializes its BC with a randomly selected back-off interval from [0, W_i-1] where W_i is the current contention window (CW) size and i is the back-off stage, and decrements this counter every time it senses the channel to be idle. The counter has the granularity of a back-off slot time and is stopped in case the medium becomes busy (called busy channel state) and the decrementing process is resumed when the medium becomes idle for a DIFS period again. The STA is only allowed to transmit when the back-off counter reaches zero. The value of W_i depends on the number of failed transmissions of a packet; at the first transmission attempt, $W_0 = CW_{min} = W$. After each transmission due to collision, W_i is doubled up to a maximum value, $W_m = CW_{max} = W.2^m$, where m is the number of back-off stages. Once the W_i reaches the maximum limit $CW_{max,}$ it remains at this value until it successfully transmits or reaches the retry limits. The whole collision resolution process of IEEE 802.11 DCF is known as Binary Exponential Back-off (BEB). The 802.11 DCF works in two access mechanisms; Basic access mechanism, and ready-to-send and clear-to-send (RTS/CTS) access mechanism. These both of the access modes differ in transmission procedure, while the collision resolution procedure BEB works same for both mechanisms. The Fig. 1 shows IEEE 802.11 DCF transmission procedure for both, basic and RTS/CTS mechanisms.

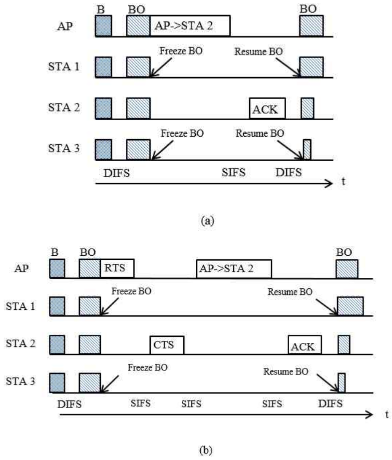

Fig. 1. IEEE 802.11 DCF Transmission Procedures; (a). Basic Access Mechanism and (b). RTS/CTS Access Mechanism

III. PERFORMANCE ANALYSIS MODEL FOR FUTURE WLANS

The role of the traditional queueing model M/G/1 is to model the queueing system of a given STA for number of packets arrival for the transmission. For simplicity of the model and calculation, we assume that there are no hidden STAs available in the WLAN, the transmission failure is only because of collision (i.e. ideal channel condition), non-saturated traffic state, and the packet arrival at each STA follows a Poisson distribution with a mean of λ packets/second. If T_s' is assumed as MAC system time of a succesful transmission, T_{que}' as the time a packet spends in the queue while waiting for the transmition, and T_{ser}' as the time duration a packet enters into a BEB procedure till it is succesfully transmitted (i.e mean service time), thus T_s' can be described as, $T_s' = T_{que}' + T_{ser}'$. And, if T_{beb}' is defined as the time duration a packet spends in BEB process, and T_x' as the time required for packet transmission at PHY layer, the mean service time (T_{ser}') can be expressed as, $T_{ser}' = T_{beb}' + T_x'$. T_{ser}' is modeled as a random variable of general distribution with a mean value of $T_{ser}' = 1/\mu$. Since packet arrival at each STA is a Poisson process with the rate λ, thus, the packet arrival and transmission at the MAC layer of each STA can be modeled as an M/G/1 queue and offered load utilization can be expressed as, $\rho = \lambda/\mu$. According to the definition in [6] for mean waiting time in queue, the MAC system time duration can be written as,

$$T_s' = \frac{\rho}{(1-\rho)}\left(\frac{T_{ser}'}{2} + \frac{T'^{2}{}_{beb}}{2T_{ser}'}\right) + T_{ser}' \tag{1}$$

Where $\rho = \lambda T_{ser}' < 1$. According to Fig. 2, in I-DTMC model, an STA moves into the (-1, 0) state (idle state) when the MAC protocol finishes its collision resolution process (i.e. BEB) and goes for a successful transmission of the given packet or if new packet arrives at the head of the MAC queue. We assume that, if p_0 is the probability of empty queue in idle state. Thus the initialization of the BEB process from idle state is due to the arrival of packet in the queue of the given STA with a probability of $(1 - p_0)$. In Fig. 2, m is used for the maximum number of retransmissions, W_i is for maximum CW size for the i-th stage, p is for the probability that the transmitted packet is collided, p_f is for the probability that the STA freezes its BEB process due to start of any other transmission. If there is a probability τ that a STA transmits in a randomly chosen slot time, from Fig. 2, it can be calculated as,

$$\tau = \frac{2(1\text{-}p_f)(1\text{-}p_0)}{(W+1)(1\text{-}p_0)+2(1\text{-}p)(1\text{-}p_f)+pW(1\text{-}p_0)\sum_{i=0}^{m\text{-}1}(2p)^i}$$

The traffic arrives with the rate λ at the MAC queue in a given slot time 'σ', thus probability of no-packet arrival can be written as, $p_0 = e^{-\lambda\sigma}$, and a transmitted packet collides when more than one STA transmits during a slot time with probability as, $p = 1 - (1-\tau)^{n-1}$ for n number of STAs. The channel is

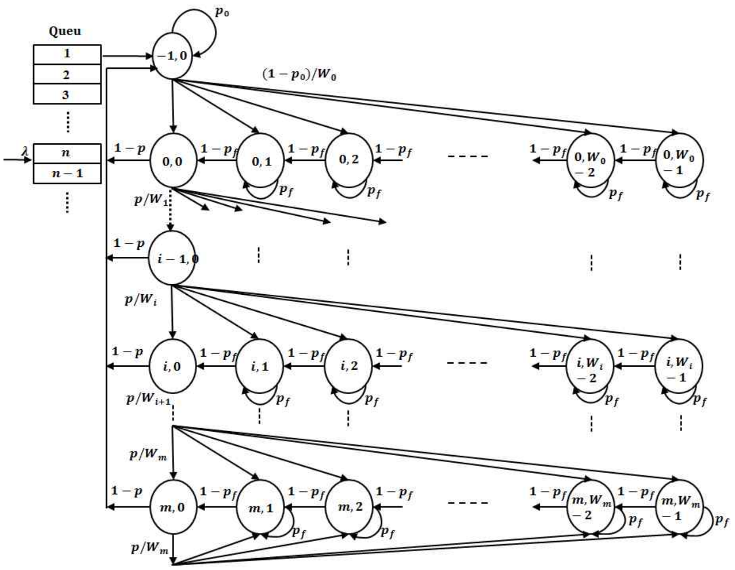

Fig. 2. State Transition Diagram for I-DTMC

detected busy and STA goes to freezing state when at least one STA transmits during a slot time. The given STA can be interrupted for two possible durations; interrupted by a succesful transmission, or interrupted by the collided transmission of more than one STA's, thus the probability that a STA goes to freezing state due to a successful transmission in the WLAN p_f^s is given by, $P_f^s = \binom{n-1}{1}\tau(1-\tau)^{n-2}$ and $P_f^s = (n-1)\tau(1-\tau)^{n-2}$. The probability that there is no transmission by other than the tagged STA (channel idle state) can be written as, $P_{idle}^{n-1} = (1-\tau)^{n-1}$. Hence, the probability that a STA goes to freezing state due to a collision of another STA in the WLAN p_f^c is obtained as, $P_f^c = 1 - P_{idle}^{n-1} - P_f^s$. Substituting the values of p, p_f and p_0 in equation for tranmission probability, we obtain one equation of an unknown parameter τ.

IV. AVERAGE MAC SYSTEM DELAY FOR PER-STA

The mean MAC system time T_s' of a tagged STA is defined as the time elapsed between the arrival of a packet into the MAC queue and successful reception of its ACK from the receiving STA. If P_{tr} be the probability that there is at least one transmission in the considered slot time for contending n STAs, it can be described as, $P_{tr} = 1-(1-\tau)^n$. If the probability P_s, is for a successful transmission that exactly one STA transmits and the remaining STAs defer transmission, thus can be written as,

$$P_s = \frac{n.\tau.(1-\tau)^{n-1}}{1-(1-\tau)^n}$$

Finally we can calculate the mean service timeT_{ser}' , which is the average packet delay of the successfully transmitted packet [4],$T_{ser}' = E[X].E[Slot]$ where $E[X]$ is the average number of slot time required for a successful packet transmission and can be found by multiplying the number of slot times. The $E[Slot]$ is the average length of a slot time required for a packet transmission. We assume d_i, the packet is delayed in each back-off stage by the probability q_i for the packet to utilize this back-off stage, and can be expressed as, $E[X] = \sum_{i=0}^{m} d_i \,.\, q_i$. An STA utilizes the average number of slot times d_i in the i stages. After few mathematical steps, we can find *E[X]* as,

$$E[X] = \frac{b_{0,0}}{2}\left[\left(\frac{(W+1)(1-2p)+pW(1-(2p)^m)}{(1-2p)(1-p)}\right)\right].$$

While, $E[Slot]$ can be written as,

$$E[Slot] = (1-P_{tr})\sigma + P_{tr}P_sT_s + P_{tr}(1-P_s)T_c + P_f^sT_s + P_f^cT_c$$

Here, σ is the duration of an empty slot, T_s and T_c are the average duration the medium is sensed busy due to a successful transmission and a collision, respectively. The T_s and T_c depends on the access mechanisms and characterized by the WLAN standards (i.e Basic and RTS/CTS), and we can describe them as,

$$T_s^{Basic} = H + E[P] + \delta + SIFS + ACK + \delta + DIFS\ .$$
$$T_c^{Basic} = H + E[P] + \delta + DIFS\ .$$
$$T_s^{RTS} = RTS + \delta + SIFS + CTS + \delta + SIFS + H + E[P] + \delta + SIFS + ACK + \delta + DIFS\ .$$
$$T_c^{RTS} = RTS + \delta + DIFS.$$

To determine the mean MAC system time using (1), we also need to calculate T'_{beb} , the mean time spent by the STA during the collision resolution, and can be given by, $T'_{beb} = T'_{ser} - T'_x$ where $T'_x = T_s^{Basic}$ for basic access mechanism, and $T'_x = T_s^{RTS}$ for RTS/CTS access mechanism, as it is the PHY layer transmission time required to transmit a packet through the PHY channel successfully.

V. NUMERICAL RESULTS

To validate our model, we have compared its results with that of the Weng's model [4] and Xu's model [5]. The values of the parameters used to calculate the numerical results for proposed and the comparing models are summarized in Table I. The system values are those specified for the Direct-Sequence Spread Spectrum (DSSS) modulation technique PHY layer. In order to assess the per-STA performance, we analyzed the average MAC system time observed by each STA individually.

TABLE I. SYSTEM PARAMETERS

Parameters	Values	Parameters	Values
Payload	1023 B	ACK	20 + PHY header = 36 Bytes
Channel Bit Rate(Mbps)	54	CTS	20 + PHY header = 30 Bytes
MAC Header	34 B	RTS	28 + PHY header = 36 Bytes
PHY Header	16 B	W_{min}	32
Propagation Delay	1 µs	W_{max}	1024
Slot Time (σ)	20 µs	m	5
DIFS	50 µs	n	5, 10, 15...45, 50
SIFS	10 µs	λ	5

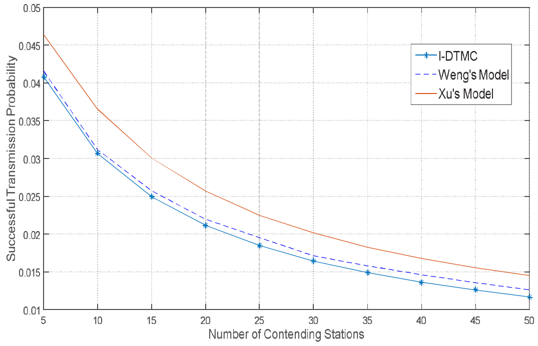

Fig. 4. Comparison of successful transmission probability

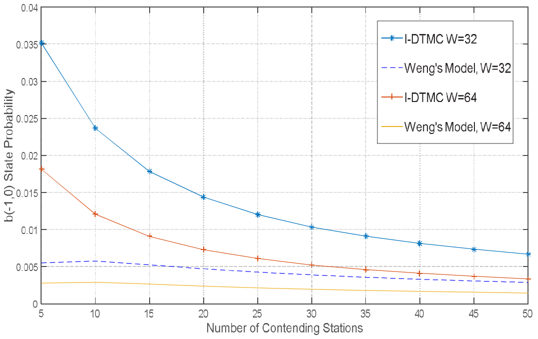

Fig. 6. Normalized state probabilities when minimum CW=32, 64

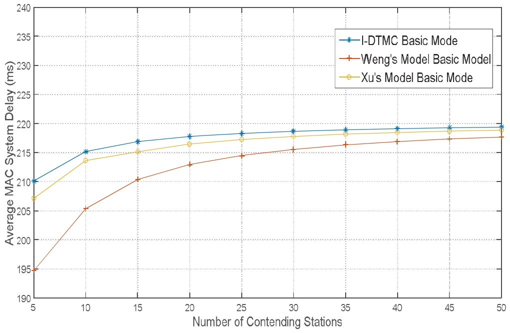

Fig. 5. Comparison of average MAC system delay in Basic Access mode

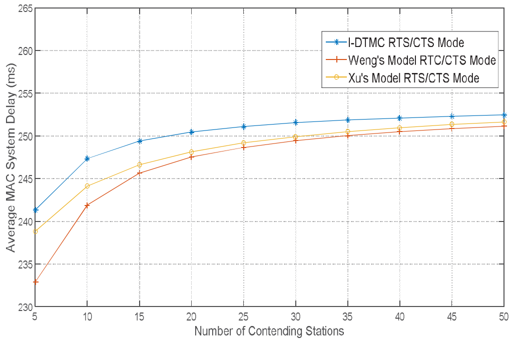

Fig. 3. Comparison of average MAC system delay in RTS/CTS Access mode

The Fig. 3 shows the successful transmission probability of the I-DTMC and other models. In figure, we observe that the comprehensive use of definations of 802.11 DCF, successful transmission changes as number of contending STAs increases. Althougt the difference between tranmission probabilities of Weng's model and I-DTMC is not much, but it indicates clearly that the miss assumption of the Weng's model has affects on transmission. The Fig. 4 is the results for normalized (-1, 0) state probability of I-DTMC as compared to the Weng's model. As we mentioned in our Section-I, the Weng's model's defination of joining first stage of the back-off process after the packet arrives for contention needs to be redefined. It can be described from the figure, that I-DTMC gives more accurate normalized state probability for (-1, 0) as compared to Weng's model.

The comparison of mean MAC system time faced by each packet for basic and RTS/CTS mechanisms in the network of the proposed I-DTMC model and models of Weng *et. al.* and Xu *et. al.* is shown in Fig. 5 and Fig. 6, respectively. A significant difference among the models can be found which clearly indicates that redefined definitions of our proposed model compared to other models have effect on the performance analysis of IEEE 802.11 DCF. The figures also show that, when we integrate Weng's model into M/G/1 queue model, initially the results obtained are much different than the model proposed by Xu and I-DTMC. It shows that the Weng's model is not suitable for the per-STA performance analysis. As larger number of STAs for both basic and RTS/CTS access mechanism, attempt to access the medium, more collision occurs and the number of retransmissions increases and the STAs suffer longer service time and stay for longer period in the MAC system.

VI. CONCLUSION

The theoretical performance in terms of MAC system delay of DCF, have already been studied by various researchers. Few of them take into account the freezing state of the STA due to transmission of other STAs during the BEB process. However, the definition used by those researchers is not suitable as it also depends upon the MAC queue (e.g. M/G/1) model. In this paper we have redefined and analyzed the BEB process model proposed by Weng *et. al*. [3] and Xu *et. al*. [4], with both basic and RTS/CTS access mechanisms. Further the modified analytical model is integrated into M/G/1 queue model as the MAC system model to analyze the performance of the single STA in terms of average MAC system time. Among our simplified and redefined analytical models, the numerical results show that redefining the assumptions have a significant effect on the performance of the IEEE 802.11 DCF. Therefore, for future WLANs it is suggested to use I-DTMC with more comprehensive use of definitions to analyze efficiency of the 802.11 DCF. In future work, we will focus on the validation of I-DTMC with simulation scenarios. An optimal CW based extension of I-DTMC is also undergo to enhance the performance of 802.11 DCF in dense WLANs.

REFERENCES

[1] Ali, R., Kim, S. W., Kim, B.-S. & Park, Y. Design of mac layer resource allocation schemes for IEEE 802.11 ax: Future directions. *IETE Technical Review* 1–25 (2016).

[2] Bianchi, G.: Performance Analysis of IEEE 802.11 Distributed Coordination Function. IEEE JSAC, vol. 18, no. 3, 535--547 (2000)

[3] Bianchi G., Tinnirello, I.: Remarks on IEEE 802.11 DCF Performance Analyses. IEEE Communications Letters, vol. 9, no. 8, 765--768 (2005)

[4] C-E Weng, C-E., Chen, H-C.: Performance evaluation of IEEE 802.11 DCF using Markov chain model for wireless LANs. Computer Standards and Interfaces, vol. 44, 144--149 (2016)

[5] Xu, C., Liu, K., Zhou, J.: Performance Analysis of Service Differentiation Schemes for IEEE 802.11 Wireless LANs in non-saturated conditions. In: 3rd International Conference on Communications and Networking in China (ChinaCom), pp. 12--16. IEEE Press, Hangzhou (2008)

[6] Zhang, X.: A New Method for Analyzing Nonsaturated IEEE 802.11 DCF Networks. IEEE Wireless Communications Letters, vol. 2, no. 2, 243--246, (2013)

[7] E. Ziouva, and T. Antonakopoulos, "CSMA/CA performance under high traffic conditions: throughput and delay analysis," *Computer Communications*, Vol. 25, no. 3, pp. 313-321, September 2002.