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Markov Model Analytics of a Wireless Local Area Network Distributed Coordination Function

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ABSTRACT

The present day heterogeneous wireless system is a hybrid of cellular, Wireless Local Area Network (WLAN) and Worldwide Interoperability Microwave Exchange (WiMAX) networks. The influence of WLAN assisted in the spread of the hybrid network to almost all facets of life cannot be over emphasized. The WLAN which is considered to be the hub of the hybrid has issues with scaling when the distribution coordination function (DCF) protocol in WLAN hotspot is used. This suggests that the DCF hotspot has problem in handling multimedia packets. Therefore, the DCF becomes the burden of this study. This work presents a robust study of the DCF protocol by applying the simple one-dimensional Markov chain. It formulates useful numerical expressions for computing the quality of service (QoS) of the WLAN utilising three scenarios. Scenario one investigated the WLAN that has infinite buffer storage capacity. A special case of a WLAN without buffer was studied in the second scenario, while scenario three presented a case with a limited buffer capacity. Equations representing nodes transmitting with equal probabilities, the expected number of counter slots between transitions as well as the probability that a backlogged station transmits in a random slot were presented. The probabilistically stochastic model was utilized in determining the collision, idle and transition probabilities, and the throughput of the WLAN DCF.

1.0 INTRODUCTION

The present day heterogeneous wireless system is a mix or hybrid of wireless communication systems and technologies. Wireless systems support the use of notebooks, mobile phones, and other handheld devices to surf the Internet, listen to music, chat, and so forth (Chen-Hag *et al.*, 2021). A good example is the IEEE 802.11-based Wireless Local Area Network (WLAN), one of the wireless technologies, which takes the lead in championing the widespread deployments of multimedia application (Najjari, 2017). It is considered to be the hub of most heterogeneous mix in terms of cost reduction and capacity enhancement. It had played vital roles in the proliferation of data networks in almost all aspects of telecommunication deployments (Hu, 2013). Research studies reported IEEE 802.11 WLAN as the most utilized wireless technology compared to long term evolution and WiMAX networks as opined by Kostas, et al., (2015). A study published by Hassan (2015) stated that WLAN is the most embraced wireless network due to its low cost, and IEEE WLAN protocol influenced the growth of mobile data three times faster than the Internet Protocol.

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Another research study presented by Anh et al. (2023) opined that the growth of WLAN is due its mobility freedom from wired and fixed connections. High transmission efficiency and good scalability were also cited as reasons for the wide use of WLAN (Jin-Ki, *et al.*, 2021). The aforementioned publication, however, noted that WLAN will in the future suffer from congestion. Abbas et al.. recorded the Internet of thing and WLAN had been deployed as smart city infrastructure enabling real-time service applications. Vivek, et al. (2022) developed a short ranged WLAN channel bounding technique simply called the channel aggregation mechanism for a suitable real-time service even though it is affected by interference. The technique supports preprocessing, optimization, increasing bandwidth and throughput parameters. The WLAN maximized radio frequency communication by applying a fair resource allocation technique to billions of contending stations (Ting-Yu, et al., 2022). A WLAN can be defined as a system of two or more computers or stations that communicate with one another using a radio access. Communication between stations of the WLAN can only occur in coverage where radio signals are received by all the stations. A station in a WLAN can only communicate with another when the channel is idle. This implies that a WLAN uses a broadcast channel where a single station transmits packets, while the others wait for the transmission to terminate before accessing the channel. Packet streams emanating from transmitting stations could be merged into a single first-in first-out (FIFO) queue when the channel is busy because packets are transmitted one at a time, and only when the channel is idle. A broadcast channel employs time division multiplexing (TDM) technique in connecting computers to a WLAN through a central point known as the access point (AP). A typical WLAN network in which stations utilized an AP to connect one another is called infrastructure mode. The infrastructure mode is the basic service set (BSS) of the WLAN, and the BSS comprises an AP and wireless devices. Communication protocols which allow maximum utilization of the channel during busy periods are useful to WLAN systems. Two or more WLAN's APs connected by a distributed portal system to a server formed the extended service set (ESS) mode. The AP could provide a communication link to both wired and wireless devices while it transfers traffic burst wirelessly to other APs as well. A WLAN where all the stations communicate without an AP is in the ad hoc mode. Each station in this mode functions as a repeater or an amplifier of a signal (Behrouz, 2016). Infrared Data Association (IrDA) and the Institute of Electrical and Electronic Engineering (IEEE), among others, are two notable organizations that manufacture WLAN devices. IrDA and IEEE WLAN implement the CSMA/CA technique which is a collision avoidance (CA) mechanism. The IEEE WLAN is a welcomed technology in Nigeria. It is used in schools, offices, homes and several business arenas. While the IEEE WLANs continue implementing the exponential back-off counter CSMA/CA, IrDA is making used of the linear back-off counter CSMA/CA. Configured WLAN operating the DCF function is gradually proliferating Federal, States, and Private Universities, homes, and small, medium, large-scale enterprises in Nigeria. This is fueled by the ease of mobility and ease of mounting and dismounting of WLAN hotspots, and the boost of wireless application services to mobile, hand-held devices. The explosive increase in the burst of traffic load emanating from devices traversing the WLAN hotspots and its impacts on the Internet are the reasons why this work modeled, and developed analytical expressions that could be used for developing the practical WLAN DCF protocol. This study used the stochastic process to determine the collision, idle and transition probabilities, and the throughput of the WLAN DCF.

A research work presents analytical models that could compute the performance of the IEEE 802.11 distributed coordination function (DCF). The model employs the binary slotted exponential backoff and provides an extensive throughput performance evaluation of the access mechanisms (Bianch, 2000). A three-state Markov-chain known as the slotted non-persistent CSMA (SNP-CSMA) was proposed for the study of interactive power network. Delay and throughput characteristics were determined using transmitter power and non- power control algorithms (Tahir, 2008). An analysis of the MAC access delay in a saturated IEEE 802.11 DCF wireless LAN was experimented on in Ali (2018). The analysis predicted the accuracy of the mean and standard deviation distribution of the access delay over a wide range of operating conditions. However, a published work by Taka and Hai (2007) demonstrated that DCF is not suitable for carrying delay-sensitive application by using a computer simulation. A solid argument which demonstrated the optimal configuration for a WLAN operating under non-saturation conditions was focused on by the researcher. Results obtained by published works revealed that a small increase in traffic intensity severely degrades the delay and throughput of a WLAN (Ali, 2018). A queue mapping algorithm known as throughput-based mapping algorithm which improves the video quality in addition to minimizing delay of video stream was projected by Chen-Han (2021).

1.1 Media Access Protocol Methods

Workstations (WSs) connected to a common wireless channel share the channel by using a distributed multiplexing algorithm. This algorithm coordinates the sharing of a wireless channel. Examples of algorithms that could be used for sharing a single wireless channel include the Aloha, slotted Aloha, Carrier Sense Media Access (CSMA), Carrier Sense Media Access with Collision Avoidance (CSMA/CA), etc., (Gallager and Bertsekas, 1992). This study focused on CSMA/CA protocol common to both the IEEE and IrDA WLANs standards. Thus, the IEEE WLAN standards were presented in the next section with a view to unveiling vital behavioral characterizations. MAC protocol utilizing CSMA/CA could be extended to measure the signal-to-interference (SIR) both in the uplink and downlink through the access point (AP) when exchanging request-to-send and clear-to-send signals. In this case only the AP operates in a full duplex mode while the work stations DCF protocol. This technique significantly improves the throughput and enhances the WLAN to operate as a hybrid transmission switching system with a low modulation code scheme (MCS) (Jin-Ki, et al., 2021). A MCS could be applied in the 5th generation and 6th generation networks. Point Coordination Function (PCF) used in IEEE 802.11 MAC protocol has been discussed in Ani and Otavboruo (2010).

2.0 Evolution of IEEE WLAN Standard

The physical and MAC sublayers of IEEE 802.11a/b/d/e/g WLAN series may be represented with the acronym IEEE 802.11x but this work resolved to maintain the trend of relatively evolving IEEE WLAN series retaining the former for a purported chronological presentation. In 1999 the task group 802.11 ratified a standard revised by the IEEE Standard 802.11-1997. The revised standard deploys infrared (IR), frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) (IEEE, 2003). The IR WLAN technology is suitable for low-cost and low-range environment. Its links operate fundamentally on intensity modulation and direct detection. However, IR radiation could be degraded significantly by multipath dispersion and attenuation (shadowing) as the workstations moved farther from the WLAN access point. The IR radiation is affected by ambient noise and electromagnetic interference. Excessive exposure to IR WLAN can cause varying levels of injuries (Valadas, 1998). The IR FHSS radio signal is implemented in the physical layer. It supports 1 Mps data rate in addition to an optional 2 Mps. But DSSS supports 1 and 2 Mps data rate (IEEE, 2003). FHSS and DSSS WLAN operate in the 2.4 GHz industrial, scientific and medical (ISM) band, they are not compatible with each other because they employ different spectrum technology (Coleman and Westcott, 2006).

Following the IEEE 802.11, in the same 1999, was the IEEE 802.11a that specified a new physical layer for the 5 GHz unlicensed national information infrastructure (UNII). It was designed to operate in the 5.15 – 5.35 GHz and 5.725 – 5.825 GHz bands with channel spacing of 20 MHz and it implements the orthogonal Frequency Division Multiplexing (OFDM) transmission technique. The IEEE 802.11a improved on the data rate of the IEEE 802.11. The use of OFDM technique on the WLAN provides payload of 6, 9, 12, 18, 24, 36, 48, and 54 Mps. The radio card of IEEE 802.11a does not communicate with the IEEE 802.11 radio card for two reasons. First, it uses a spread spectrum technology different from that of the IEEE 802.11 devices. Second, it transmits in the 5 GHz UNII band, instead of the 2.4 GHz ISM band utilized by the IEEE 802.11 WLAN. However, the IEEE 802.11a can coexist with the IEEE 802.11 in the same physical space because they transmit data in separate frequency ranges (Coleman and Westcott, 2006).

Later in the same 1999, the IEEE task group published the IEEE Std. 802.11b-1999 that was corrected and presented as IEEE Std. 802.11b-1999/Cor1-2001. The group established the complementary code keying (CCK) that has the capability to transmit data at the rates of 5.5 and 11Mps in the 2.4 - 2.4835 GHz ISM band in addition to the 1 and 2Mps of IEEE 802.11 band. The IEEE 802.11b occupies the same 2.4 GHz band channels as the IEEE 802.11. Higher Rate DSSS (HS-DSSS) proposed by the group transmits payload at a rate between 5.5 and 11Mps. The task group initiated a combination of packet binary convolution coding (PBCC) and DSSS that grant data throughputs of 2, 5.5 and 11 Mps (IEEE, 2007). The IEEE 802.11b does not provide a backward compatibility with the IEEE 802.11 FHSS WLAN. However, it is compatible with the IEEE 802.11 DSSS WLAN.

802.11e, an IEEE WLAN standard, extended the MAC protocol to support the IEEE WLAN with reliable quality of service (QoS) requirements. The standard supports transmission of various traffic types over WLAN. In order to improve WLAN's QoS, IEEE 802.11e specified the Hybrid Coordination Function (HCF) which enables prioritized and parameterized packets at the MAC layer. The HCF multiplexed the Distributed Coordinated Function (DCF) and the Point Coordination Function (PCF). The ratified DCF is named Enhanced Distributed Channel Access (EDCA) while the ratified centralized polling-based channel PCF is branded HCF Controlled Channel Access (HCCA) (Ramos and Dey, 2005; Perez-Costa and Campus-Mur, 2010). The EDCA presented in the IEEE 802.11e standard introduced access categories (ACs) for different traffic by applying priorities to packets. Traffic assigned low priority values are given high transmission priority than those with high priority values (Sebastein, 2003). It supports four ACs- voice, video, audio and background. Each ACs is configured with Arbitration Inter-frame Spaces (AIFS) (Perez-Costa and Compus-Mur, 2010). A change in any of the ACs affects the QoS of a WLAN

Another group named IEEE 802.11g introduced the DSS-OFDMA modulation that provides additional payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mps on IEEE WLANs (IEEE std, 2003). The group introduced the extended rate physical layer binary convolution coding (PBCC) which is rarely used. IEEE 802.11g has a backward compatibility with the 1, 2, 5.5, and 11Mps DSSS. The IEEE 802.11g access point communicates with 802.11a client stations as well as the IEEE 802.11b stations.

2.0 IEEE WLAN AND IRDA MEDIUM ACCESS CONTROL (MAC) PROTOCOL

The legacy IEEE 802.11 WLAN used the default contention aware DCF (CSMA/CA) protocol and it can be switched to the contention free PCF protocol. In DCF, a workstation (WS) that has data to transmit first of all chooses a minimum exponential backoff contention window (CW_{min}). Then, it performs carrier sensing of the channel to determine its current state. The WS defers its data transmission if the medium is busy serving a request. It does this by freezing its backoff counter during busy periods. When the medium becomes idle again, the WS unfreeze its backoff counters and resumes counting. It counts down to zero and wait for a short period of time known DCF inter-frame space before transmitting. After a successful transmission the WS returns its counter to the default CW_{min} for every acknowledgement it receives from a sink; recall that the receiving WS (sink) sent an acknowledgement after a short inter-frame space (SIFS) (Ting-Yu, et al. 2012). However, a WS keeps doubling its contention window (CW) size if collisions persist. When the CW of a WS reaches the maximum contention size, and transmission is still unsuccessful the packet of the WS is dropped (Cheng and Wu, 2009; Lin et al., 2012). The fundamental operation described above is suitable for best effort transmission such as Internet data (Qiang, 2005). However, DCF technique does not guarantee successful packet transmission. The procedure for transmitting a frame is improved upon by compelling the WS to make a request to the destination station before transmitting packets. This request tagged request-to-send (RTS) is acknowledged after a short interval known as short inter-frame space (SIFS) by the sink. The acknowledgement known as clear-to-send (CTS) indicates the readiness of the sink to receive data. This four-way handshake - RTS, CTS, data transmission and acknowledgement protocol - further reduces collision and combats hidden terminals in a WLAN. A WS is allowed to send frames if it receives the correct CTS, otherwise packets sent by the WS could collide with packets from other stations. The MAC protocol was later enhanced by introducing enhanced distributed channel access (EDCA). Stations apply a combination of CW and arbitration interframe space (AIFS) of EDCA before transmitting packets. Stations with high priority use short CW and AIFS whereas stations with low priority utilize long CW and AIFS. The EDCA provides a contention-free access to a wireless channel in an interval known as transmission opportunity (TXOP). Detail explanation is presented in (Beefing et al., 2014). In the case of IrDA WLAN, a contending station initializes collision avoidance slot, a linear back-off counter, before sending RTS to a receiver. The supposed receiver waits for a minimum turn-around time (TAT), and responds by transmitting CTS to the source station. Data is then transmitted by the source station to the sink after the TAT. End-of-burst packet is forwarded to the receiver signaling the end of data, and the receiver reciprocates by responding with end-of-burst-confirmation (Chatzimisios, 2006).

The CSMA/CA protocols developed by both technologies have some similarities.

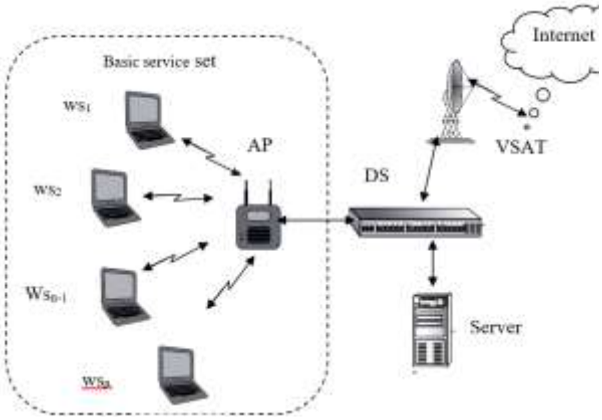
DIFS is similar to CAS, SIFS is analogous to TAT, and acknowledgement is equivalent to End-of-burst packet. Similarity in this context does not imply in any sense, as an instance, that the size of DIF is equal to CAS; it implies that the protocols of both technologies share some common corresponding features and principle of operations.

2.1 Limitation of IEEE WLAN-DCF

Some papers noted that the poor performance of the IEEE 802.11 WLAN was as a result of the MAC protocol (Lin, 2011). It has also been stated in literatures that one weakness of the original IEEE 802.11, towards efficient support for multimedia traffic, was the lack of enhanced QoS provisioning in the MAC layer (Dimitris, 2006). Proposed service such as the IP-level service differentiation was not sufficient to efficiently manage the shared resources of IEEE 802.11x. Additional QoSs provisioning at the MAC layer are required. To a large extent, the capability of DCF supporting the traffic of QoS-sensitive applications has been detailed in (Abdelhamid, 2007; Zhai et al., 2006). When arriving traffic heavier than the capacity of the WLAN enters the DCF, saturation occurs and this results to a significant increase in delay and a corresponding decrease in throughput. Provisioning of QoS to upper layers protocols poses serious challenges to the DCF of MAC protocol. The DCF only supports best effort service where independent stations compete for the channel with the same priority, but it cannot provide a guaranteed service for real-time and multimedia traffic (Lee, et al., 2009). The contention window of MAC does not support guaranteed QoS unless the network load and parameters are tuned such that it (the WLAN network) operates in non-saturated state (He, 2010). Also, the binary exponential back-off caused a heavy-tailed delay on the DCF in the case of unlimited retransmissions. This suggests that DCF protocol work best in small WLAN network. Therefore, investigation of the QoS parameters in this research is based on a small WLAN setup. The limitations of WLAN cited by literature refer to the MAC protocol and the CSMA/CA as well by implication. In order to overcome the limitations, it will be a good idea to model the DCF mathematically by converting the WLAN architecture to graphical Markov rate-based chain. Numerical expressions synthesized from the chain offers are developed from tractable mathematical principles and stochastic probabilistic processes.

3.0 WLAN MODEL

Figure 3.1 depicts the basic architecture of the WLAN and the WLAN-DCF model used for the study of a typical WLAN network. It consists of WSs, the WLAN access point (WLAN-AP), distribution system (DS), a server and a very small aperture terminal (VSAT). The access point (AP) transmits data wirelessly between the WS and the wired network infrastructure. It supports users and provides coverage for the BSS at a specified radius. The WSs are placed close to the WLAN-AP to ensure a good reception of radio signals between the WLAN and WSs (Ting-Yu, 2012). The flowchart of the WLAN DCF protocol is shown in Figure 3.2. The flowchart focused more on the traffic signals of the wireless medium. Signals such as the RTS, CTS, packet data and acknowledgment of the CSMA/CA protocol are indicated as shown in the figure. The DIFS (or CAS) and SIFS (or TAT) as well as the back-off algorithm, though vital, where not considered in the medium in formulating tractably analytical expressions.



WS – workstation
DS – distribution system
VSAT – very small aperture terminal

Figure 3.1a: Architecture of a basic service set WLAN network (Ani and Otavboruo, 2010)

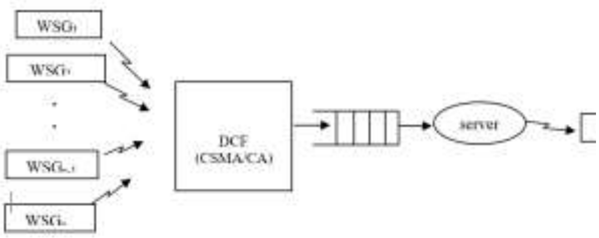
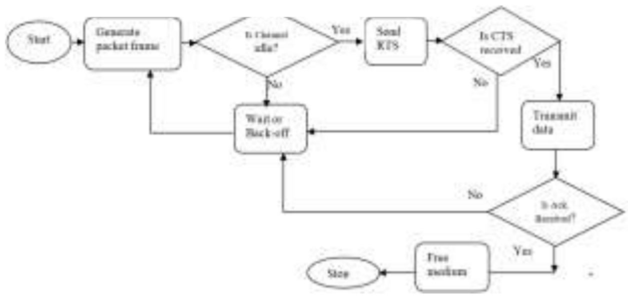


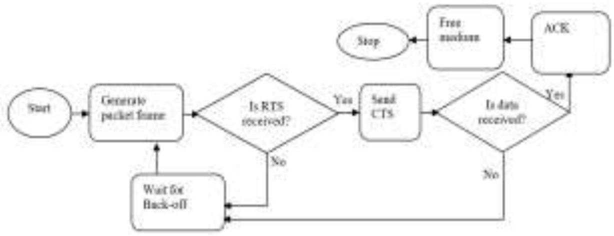
Figure 3.1b: One Direction Link WLAN-DCF Model

Figure 3.1: Architecture and Model of WLAN-DCF

This research modified the non-persistent CSMA as well as the one-persistent CSMA presented in Kleinrock (1975), and added the collision avoidance (CA) mechanism to the CSMA. This modification named CSMA/CA was redefined mathematically. Instead of the usual single collision period, idle and successful states established in Abbas (2021), this work included a multiple-collision, idle and multiple-successful transmission states to the existing one-dimension Markov chain. Packet transmission is enhanced by attaching a buffer to the transmitter; the buffer stores packets when the transmission unit is busy processing a packet. In addition, when the transmitter is busy and the buffer is filled up, successive arriving packets are dropped by the buffer. During packet transfer between two WSs, the other non-transmitting WSs compute the transmission time of the wireless medium by contacting the network allocation vector (NAV). After computing the transmission time, the non-transmitting WSs freeze their counters until after either the packet transmission is completed or the NAV timer expires. In cases of collision between two or more systems, a CTS time-out or a negative acknowledgment (NAK) is sent to all WSs and the channel becomes free again. WSs that freeze their counter resume sensing the channel and start counting down. A station that counts down to zero …packet … short interval and the channel is still idle. The whole process of successful transmission is illustrated in the flowchart of Figure 3.2, while the collision aspect is included in the Markov chain of Figure 3.3. The expression for collision probability, transmission, throughput, and resource utilization are derived from Figure 3.3.



(a): Signal flowchart of CSMA/CA at the transmitter



(b): Signal flowchart of CSMA/CA at the Receiver

Figure 3.2: Signal flowchart of CSMA/CA from Transmitter/Receiver's side

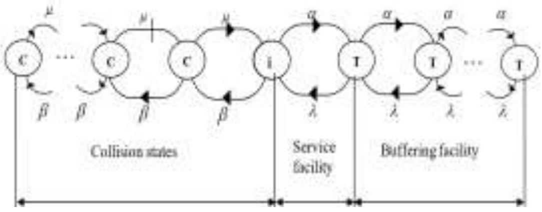


Figure 3.3: Rate-based Markov chain of the CSMA/CA of DCF WLAN model

Equations (3.1 to 3.8) are the step-by-step state transition/collision expressions derived from Figure 3.3.

State: Transition probability. Subsequent sessions formulate the QoS parameters of the DCF for different WLAN scenarios.

$$[C_n]: \quad \mu P_{Cn} = \beta P_{C_{n-1}}; \quad P_{C_{n-1}} = \frac{\mu P_{Cn}}{\beta}$$
(3.1)

$$[C_{n-1}]: (\mu+\beta)P_{Cn-1} = \mu P_{Cn} + \beta P_{C_{n-2}} \quad P_{C_{n-2}} = \frac{\mu P_{C_{n-1}}}{\beta} = \left(\frac{\mu}{\beta}\right)^2 P_{Cn} \quad (3.2)$$

Equation (3.3) is produced by substituting Equation (3.1) into Equation (3.2)

$$P_{C_{n-2}} = \frac{\mu P_{C_{n-1}}}{\beta} = \left(\frac{\mu}{\beta}\right)^2 P_{Cn} \quad (3.3)$$

Application of the principle of mathematical induction to the states above produced the state equation probability given in Equation (3.4)

$$P_C(i) = \begin{cases} \left(\frac{\mu}{\beta}\right)^i P_{C_n} \quad i = 1, 2, 3, \ldots, j \\ \left(\frac{\mu}{\beta}\right)^S \left(\frac{\alpha}{\lambda}\right)^k \quad k = 0, 1, 2, 3, \ldots; S = j+1 \end{cases} \quad (3.4)$$

Where,

i = Numbers of collision occurrence
k = Numbers of successful transmission
α = Arrival rate of packets (Successful transmission)
λ =Transmission rate of the WLAN DCF
β = Backoff
μ =Collision resolution
T_n = Successful transmission n packets
C_n = The n^{th} collision

By applying of the principle of probabilistic normalization to Equations (3.5) and (3.6) the expression in collision probability represented is obtained in Equations (3.7 and 3.8).

$$P_{C_n} + P_{C_{n-1}} + \ldots P_{C_1} + P_{T_1} + P_{T_2} \ldots + P_{T_n} = 1 \quad (3.5)$$

$$\left(\sum_{i=0}^{j-1}\left(\frac{\mu}{\beta}\right)^i P_C(i) + \sum_{k=0}^{m}\left(\frac{\mu}{\beta}\right)^j \left(\frac{\alpha}{\lambda}\right)^k P_C(i)\right) = 1$$
(3.6)

$$P_C(i) = \left(\sum_{i=0}^{j-1}\left(\frac{\mu}{\beta}\right)^i + \sum_{k=0}^{m}\left(\frac{\mu}{\beta}\right)^j \left(\frac{\alpha}{\lambda}\right)^k\right)^{-1} \quad (3.7)$$

$$P_C(i) = \left(\sum_{i=0}^{j}\left(\frac{\mu}{\beta}\right)^i + \sum_{k=1}^{m}\left(\frac{\mu}{\beta}\right)^j \left(\frac{\alpha}{\lambda}\right)^k\right)^{-1} \quad (3.8)$$

Equation (3.8) is thus the generalized analytical expression formulated from the Rate-based Markov chain of the DCF WLAN model depicted in Figure 3.3.

Proof:

$$\sum_{k=0}^{m}\left(\frac{\mu}{\beta}\right)^j \left(\frac{\alpha}{\lambda}\right)^k = \left(\frac{\mu}{\beta}\right)^j + \sum_{k=1}^{m}\left(\frac{\mu}{\beta}\right)^j \left(\frac{\alpha}{\lambda}\right)^k$$

$$\sum_{i=0}^{j}\left(\frac{\mu}{\beta}\right)^i = \sum_{i=0}^{j-1}\left(\frac{\mu}{\beta}\right)^i + \left(\frac{\mu}{\beta}\right)^j$$

4.0 CASE STUDY OF WLAN DCF

The generalized analytical expression presented by Equation (8) formed the base on which three DCF WLAN models were formulated. These models are useful for academic, industrial and scientific purposes. The collision and transition probabilities and throughput expressions were determined in all the scenarios modeled.

4.1 Scenario one: single collision and transmission and infinite buffer state

Scenario one modeled the CSMA/CA algorithm of the WLAN transceiver with a Markov chain that presents an idle, one collision and one transmission and infinite buffer states. It presents graphically C_1, I, T_1 and an infinite buffer capacity in Figure 3.3. Speaking in a numerical sense, $j=1, k=\infty$ is applied to Equation (4.1) and the expression for $P_C(i)$ becomes:

$$P_C(i) = \left(1 - \frac{\mu}{\beta} + \frac{\mu}{\beta}\sum_{k=0}^{\infty}\left(\frac{\alpha}{\lambda}\right)^k\right)^{-1} \quad (4.1)$$

The application geometric law to Equation (4.1), resulted in the expression of collision probability derived in Equation (4.2).

$$P_C(i) = \left(1 + \frac{\mu}{\beta}\left(\frac{\alpha}{\lambda - \alpha}\right)\right)^{-1} \quad (4.2)$$

Major chain specified by scenario one was used The idle, successful transmission probabilities and throughput expressions of the CSMA/CA presented in Equations (4.3to 4.5).

$$P_i = \frac{\mu}{\beta}P_C(i) = \frac{\mu}{\beta}\left(1 + \frac{\mu}{\beta}\left(\frac{\alpha}{\lambda - \alpha}\right)\right)^{-1} \quad (4.3)$$

$$P_T = \frac{\alpha}{\lambda}P_i = \frac{\alpha}{\lambda}\frac{\mu}{\beta}\left(1 + \frac{\mu}{\beta}\left(\frac{\alpha}{\lambda - \alpha}\right)\right)^{-1} \quad (4.4)$$

$$S = \alpha P_T = \frac{\alpha^2}{\lambda}\frac{\mu}{\beta}\left(1 + \frac{\mu}{\beta}\left(\frac{\alpha}{\lambda - \alpha}\right)\right)^{-1} \quad (4.5)$$

4.*2 Scenario two: single collision and infinite transmission*

The scenario established the DCF protocol without the inclusion of buffering facility. It formulated a mathematical expression for the CSMA/CA protocol with a Markov chain that has one collision, idle and transmission state. This implies that $j=1, k=1$ is applied to Equation (3.8) to derive the expression of $P_C(i)\, P_i$, P_T *and* S as shown in Equations (4.6 to 5.0).

$$P_C(i) = \left(1 + \frac{\mu}{\beta} + \frac{\mu}{\beta} \times \frac{\alpha}{\lambda}\right)^{-1} \quad (4.6)$$

$$P_C(i) = \left(1 + \frac{\mu}{\beta}\left(\frac{\lambda + \alpha}{\lambda}\right)\right)^{-1} \quad (4.7)$$

$$P_i = \frac{\mu}{\beta}P_C(i) = \frac{\mu}{\beta}\left(1 + \frac{\mu}{\beta}\left(\frac{\lambda + \alpha}{\lambda}\right)\right)^{-1} \quad (4.8)$$

$$P_T = \left(\frac{\mu}{\beta}\right)\left(\frac{\lambda}{\alpha}\right)P_i = \left(\frac{\mu}{\beta}\right)\left(\frac{\lambda}{\alpha}\right)\left(1 + \frac{\mu}{\beta}\left(\frac{\lambda + \alpha}{\lambda}\right)\right)^{-1} \quad (4.9)$$

$$S = \alpha\left(\frac{\mu}{\beta}\right)\left(\frac{\lambda}{\alpha}\right)\left(1 + \frac{\mu}{\beta}\left(\frac{\lambda + \alpha}{\lambda}\right)\right)^{-1} \quad (4.10)$$

Packets are transmitted by a given node with a probability (η_n). If all nodes have equal chances of transmitting, the probability that transmission does not occur in any node is simply computed by Equations (4.11) and (4.12) as shown in Tahir and Mazunder (2008).

$$\gamma = \prod_{i=1}^{n}(1 - \eta_n) \quad (4.11)$$

Given that $\eta_1 = \eta_2 ... = \eta_n = \eta$, then the probability that there is no packet transmission is:

$$\gamma = \left(1 - \frac{2}{W+1}\right)^n \quad (4.12)$$

Where,
i = number of nodes in a slot

The expected number of counter slot E[Z] spent in each state between transitions and the probability that a backlogged station transmits (τ) in a random slot can be expressed as shown in Equations (4.13 and 4.14) (Vukovic and Smavatkul, 2004).

$$E[Z] = 1 + \sum_{i=0}^{m}\frac{2^i W - 1}{2}P_C(i) \quad (4.13)$$

$$\tau = \frac{1}{E[Z]} = \frac{1}{1 + \sum_{i=0}^{m}\frac{2^i W - 1}{2}P_C(i)} \quad (4.14)$$

Where,

m = Maximum number of backoff stage
W= contention Window
i = 1, 2, … m

4.3 Scenario three: multiple collisions and multiple transmissions

Scenario three depicts a typical experimentation with seven WS connected to WLAN operating the DCF (CSMA/CA) protocol. Synthesis of the scenario is focused on the idle, collision and a single transmission state, and a first-in-first-out (FIFO) queue that stores a maximum queue length of six packets. The expression for collision probability is given in Equation (4.15). After applying geometric series to Equation (4.15), the collision, idle and successful transmission probabilities, and the throughput expression are presented as shown in Equations (4.16 to 4.19).

$$P_C(i,k) = \left(\sum_{i=0}^{2} \left(\frac{\mu}{\beta} \right)^i + \left(\frac{\mu}{\beta} \right)^3 \sum_{k=0}^{7} \left(\frac{\alpha}{\lambda} \right)^k \right)^{-1} \quad (4.15)$$

$$P_C = \left(\sum_{i=0}^{2} \left(\frac{\mu}{\beta} \right)^i + \left(\frac{\mu}{\beta} \right)^3 \frac{\left(1 - \left(\frac{\alpha}{\lambda} \right) \right)^8}{1 - \left(\frac{\alpha}{\lambda} \right)} \right)^{-1} \quad (4.16)$$

$$P_i = \left(\frac{\mu}{\beta} \right)^3 P_C = \left(\frac{\mu}{\beta} \right)^3 \left(\sum_{i=0}^{2} \left(\frac{\mu}{\beta} \right)^2 + \left(\frac{\mu}{\beta} \right)^3 \frac{\left(1 - \left(\frac{\alpha}{\lambda} \right) \right)^8}{1 - \left(\frac{\alpha}{\lambda} \right)} \right)^{-1} \quad 4.17)$$

$$P_T = \left(\frac{\mu}{\beta} \right)^3 \left(\frac{\alpha}{\lambda} \right)^7 \times P_C = \left(\frac{\mu}{\beta} \right)^3 \left(\frac{\alpha}{\lambda} \right)^7 \left(\sum_{i=0}^{2} \left(\frac{\mu}{\beta} \right)^2 + \left(\frac{\mu}{\beta} \right)^3 \frac{\left(1 - \left(\frac{\alpha}{\lambda} \right) \right)^8}{1 - \left(\frac{\alpha}{\lambda} \right)} \right)^{-1} \quad (4.18)$$

$$S = \alpha P_T = \left(\frac{\mu}{\beta} \right)^3 \left(\frac{\alpha}{\lambda} \right)^7 \times P_C = \alpha \left(\frac{\mu}{\beta} \right)^3 \left(\frac{\alpha}{\lambda} \right)^7 \left(\sum_{i=0}^{2} \left(\frac{\mu}{\beta} \right)^2 + \left(\frac{\mu}{\beta} \right)^3 \frac{\left(1 - \left(\frac{\alpha}{\lambda} \right) \right)^8}{1 - \left(\frac{\alpha}{\lambda} \right)} \right)^{-1} \quad 4.19)$$

5 CONCLUSIONS

This work modeled CSMA/CA protocol of IEEE WLAN DCF with a simple one-dimension Markov chain and presented analytical expressions for three scenarios. Scenario one investigated a WLAN with infinite buffer state. A special case of a WLAN without buffer was studied in the second scenario, while scenario three presented a case with a small buffer state. Equations representing case of nodes transmitting with equal probabilities, and the expected number of counter slots in each state between transitions and the probability that a backlogged station transmits in a random slot was also presented. Flow charts transmission/ reception and the entire expressions presented by the work are of immense importance to computer scientists who seek to develop event-base algorithm using programming languages. This work opens a new vista for addendum (Part two) of the CSMA/CA WLAN DCF which is currently being simulated for burst traffic sources. The author of this publication is aiming at comparing the analytical results with the simulation results of the CSMA/CA. The part two, to be presented shortly, modeled the influence of burst sources on WLAN CSMA (DCF function) using MATLAB's SimEvent /workspace environments.

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