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Enhancing the throughput performance of IEEE 802.11b under saturated traffic distribution

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Abstract The last decade has witnessed rapid growth in the deployment of wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard. The IEEE 802.11 Wireless LAN (WLAN) has become a dominant technology for the (indoor) broadband wireless networking. The popularity of IEEE 802.11 networks comes with its low cost, high data rate and seamless handoff. Along with its success, there have been demands to enhance the performance of the IEEE 802.11b. To meet such needs, the IEEE 802.11 Working Group (WG) has been developing new protocols to amend the existing protocols. In general, IEEE 802.11b networks operate on either PCF (Point co-ordination function) or DCF (Distributed co-ordination function) mode. This research work mainly focuses on DCF mode for IEEE 802.11b standard. Real time measurement of an existing network performance (throughput) was carried out. WLAN performance analysis was presented. The study was carried out to establish the influence of number of workstations and traffic distribution/patterns on IEEE802.11b QoS parameters. WLAN network model was developed and simulated using MATLAB Simulink environment. The result showed that the performance of IEEE 802.11b WLAN deteriorate as the traffic loading increases and that Gamma Traffic Distribution has the best performance in terms of throughput than the Exponential and Geometric Traffic Distributions. The Real time measurement of throughput result was used to validate our proposed Matlab model.

Keywords Matlab, WLAN, IEEE802.11b, Network, Throughput, Real Time, DCF, VSAT, QoS and Traffic

1. Introduction

IEEE 802.11 Wireless LANs (WLANs) have been extensively deployed in the recent years in many different environments for enterprise, home, and public networking. But it cannot provide QoS support for an increasing number of multimedia applications, due to this drawback, an in-depth analysis of WLAN access protocol and Quality of Service are necessary. In order to provide a sufficient QoS for real time applications, the transfer service should be carried out via different priorities. However, the objective of the study is to optimize the throughput performance of IEEE 802.11b under saturated traffic distribution.

The 802.11 standard specifies the protocols for both the medium access control (MAC) sub-layer and physical (PHY) layer. Three medium access coordination functions are defined in the original 802.11 MAC: a mandatory distributed coordination function (DCF), an optional point coordination function (PCF) and the combination of DCF and PC. DCF uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol, and it is best known for asynchronous data transmission. PCF uses a central-controlled polling method to support synchronous data transmission [1]. Up till now, only DCF is implemented in most application devices [2]. The IEEE802.11 wireless networks can be configured into two different modes: ad hoc and infrastructure modes. In ad hoc mode, all wireless stations within the communication range can communicate directly with each other, whereas in infrastructure mode, an access point is needed to connect all stations to a Distribution System, and each station can communicate with others through the access point [3]. The IEEE 802.11 DCF can only provide best-effort services without any QoS guarantee [4]. In DCF, every station statistically has the same probability to access the channel and transmit no matter what kinds of traffic they are sending. Obviously, this kind of channel access mechanism is challenged by time bounded services, such as VoIP, video conferencing, requiring guaranteed bandwidth, delay and jitter. Without prioritized traffic, a station may have to wait an arbitrarily long time before it gets the chance to transmit so that these real-time applications may suffer [4]. One of the most important studies was proposed by Bianchi [5]. He proposed a Markov chain model to compute the saturation throughput performance and the probability that a packet transmission fails due to collision. The backoff mechanism of IEEE 802.11 was studied under heavy traffic condition. It was analyzed that the throughput and delay of CSMA/CA protocol under maximum load conditions by using a bi-dimensional discrete Markov chain [6]. Chao *et al.,* [7] proposed a simple load-aware MAC protocol. Observing that the contention based IEEE 802.11 DCF scheme does not perform well and often renders excessive collisions (and subsequent retransmissions) when the system load is heavy, they propose to use IEEE 802.11 DCF when the overall system load is light, and a token based, contention-free scheme otherwise. Kwon *et al.* [8] proposed to use a minimum CW size *CWmin* that is smaller than what is specified in IEEE 802.11 and a maximum CW size *CWmax* that is larger than what is specified in IEEE 802.11. Each station increases (doubles) the CW size up to *CWmax* when it detects a busy medium or when it experiences collisions in its transmission attempt, and decreases (halves) its current backoff timer value when it detects a fixed number of consecutive idle slots during the backoff procedure. The CW size is reset to *CWmin* when it successfully transmits a frame. However it is not clear whether or not the approach provides deterministic performance bounds in terms of system throughput and frame delays. While the above works provide important insights and useful points of reference or comparison for this work, none of the above works used a real time experiment to compare their proposed model. In this work, Real time measurement of the throughput performance of an existing network was carried out and analyzed. More so, an analytical Matlab model of IEEE 802.11b using DCF mechanism was developed; the model was used to compute the throughput against number of workstations in the absence of hidden stations and transmission errors, a more comprehensive analysis using different traffic distribution to analyze the effect of saturated traffic on the throughput of a WLAN was provided. The result was used to compare the resulted obtained from real time measurement.

Distributed Coordination Function (DCF): DCF is based on the carrier sense multiple access with collision avoidance (CSMA/CA) channel accessing mechanism. The DCF operation mode consists of two techniques for packet transmission. The default scheme is a two-way handshaking technique where a positive acknowledgment is transmitted by the destination station upon successful reception of a packet from the sender station. The reason for an ACK is that the sender cannot determine whether its transmission is successful only by listening to its own transmission.

If the medium is busy, it makes no sense for a station to transmit its frame and cause a collision and waste band-width. Instead the station should wait until the channel becomes idle. When this happens, there is another problem: Other stations may have also been waiting for the channels to become idle, then collisions are likely to occur; and because collision detection is not possible, the channel will be wasted for entire frame duration [9]. A solution to this problem is to randomize the times at which the contending stations attempt to seize the channel. This approach reduces the likelihood of simultaneous attempts and hence the likelihood that a station can seize the channel [9].Another scheme involves a four-way handshaking technique known as request-to- send/clear-to-send (RTS/CTS) mechanism. By this scheme, the sender first sends the RTS to reserve the channel before its transmission, and upon receiving CTS from the receiver, the normal packet transmission and the ACK response proceeds [10].

Qos Limitations of DCF and Enhancement: In DCF, only best effort service is provided. Time-bounded multimedia applications (e.g., voice over IP, video-conferencing) require certain bandwidth, delay, and jitter guarantees. The point is that with DCF, all the STAs compete for the channel with the same priority. There is no differentiation mechanism to provide better service for real-time multimedia traffic than for data applications. Differentiation mechanism is based on the thought that of different applications should be served distinctively in different classes. There are two modes of differentiation service; priority based service and fair scheduling service. The classification mechanism is designed to provide prioritized QoS by enhancing the contention-based DCF. Before entering the MAC layer, each data packet received from the higher layer is assigned a specific user priority value. At the MAC layer, the mechanism introduces first-in first-out (FIFO) queues mechanism and access categories (ACs). Each data packet from the higher layer along with a specific user priority is mapped into a corresponding AC. Different kinds of applications (for example, background traffic, best effort traffic, video traffic, and voice traffic) will be directed into different ACs. Therefore, each flow is handled selectively. Priority based service always serve those flows with the highest priority than the remaining ones. This was implemented in the IEEE 802.11b Matlab Simulink MAC DCF protocol developed.

Real Time Network Performance Measurement: Two different network sniffer software were used to carry out the measurement. The measurement of throughput was taken at intervals as the number of user's increases or decreases. The software used are NetStress and Jperf.

Netsreess: NetStress is a tool used to measure network performance, both wired and wireless. It is a simple tool that employs bulk data transfer using layer 3 protocols (TCP and UDP). Network performance is reported in terms of throughput; that is, bits (or bytes) per second. NetStress includes the following features: supports both TCP and UDP data transfers; supports multiple data streams; variable TCP / UDP segment size; rate of packet transmission (Packets Per Second); variable Maximum Transmission Unit (MTU); uplink and downlink modes; choice of display units (KBps, Kbps, MBps, Mbps).

In order to measure throughput performance between two nodes on a network we need a transmitter and receiver. Packets are transmitted to the receiver, and the receiver, in turn, sends the result back to the transmitter. The results represent a quantifiable metric that reflects the performance of the path between the transmitter and receiver machines. By selecting the transmitter and receiver machines at various points within the network one can analyze critical portions of the data path.

Jperf: JPerf is a graphical front end for the popular network testing tool Iperf. Using JPerf you can quickly test a WAN or LAN connection to determine the network throughput and delay. The test results are automatically graphed and presented in a format that is easy to read. JPerf can also be used to detect packet loss, delay, jitter, and other common network problems. JPerf is designed to run as a client/server application. By default, JPerf runs in TCP mode and listens on port 5001.

More so, there are several TCP options that can be modified such as buffer length, window size, and Round trip Time. JPerf has a cool ability that allows you to select a file to be transmitted to the server during the test. This function allows you to simulate a real world data transfer across your network in a controlled manner.

Experimental Environment: This experiment was carried out at Chams Plc office (Old Secretariate Building By Arroma Junction) Awka, it's an indoor environment. Three different cases were considered in the experiment. Their network is divided into three regions namely; Data Capture Center (Ground Floor), Data Update Center, and Data upload/card center which also houses the main Server. These three regions have different ranges from the access points. Each of these centers house are between 15 to 40 fixed desktop computers and few laptops. Some mobile smart phones were also used as host. All the systems have wireless LAN features and are IEEE 802.11b compliant.

The network was transmitted to the three regions, each via Nanostation M5 radio, which brings the network to the wireless Cisco router and distributed via a wireless AP and a LAN switch (LinkSys).

These three Centers are located in the same building but are separated with few meters way from each other. The measurements are carried out in these three locations. In all the three regions, two different network sniffer software (NetStress and Jperf) were used to take measurement on the network.

Test bed one: Data upload/card Center: The first experiment was carried out in Data upload/card Center which houses the main servers. The Data upload/card Center is located on the first floor of the old secretariat two storey building and was used for the measurements; first was with five hosts, second was with ten host, third was with 15 and it continues in that order till we have fifty work stations. The measurement of throughput was carried out using the two different network sniffers, one at a time.

Test bed Two: Data Update Center: The second experiment was carried out in Data Update center, which is about 50meters from the data upload center. It's also located at the 2nd floor of the building. The same procedure was also used here to carry out measurements in this center. In the first scenario, five hosts were used; as the second ten were used; in the third fifteen were used and so on up to fifty work stations. The readings were recorded (throughput).

Test bed Three: Data Capture center: The third experiment was carried out in the data capture center which is located at the ground floor of the building. It's about 100meters away from the Data Upload center. Signal measurements were taken and recorded accordingly. Five host were used in the first scenario; ten were used in the second scenario while fifteen, twenty, and up to fifty work stations were used respectively. Measurements were carried out on each of the test beds using two network sniffers viz; NetStress and Jperf.

Throughput Calculation: Throughput is defined as the number of bits passing through a point in a second or it is defined as the number of packet passing through the network in a unit time. [8]

Throughput =Total number of bits offered by UTs – number of bits pending (unserved) – number of bits dropped.

$$= (\text{bits\_offered}) - (\text{bits\_pending}) - (\text{bits\_dropped}) \qquad (1)$$

Also,

$$\text{Throughput} = \frac{\text{File Size}}{\text{Transmission Time (bps)}} \qquad (2)$$

$$\text{Max. TCP throughput} = \frac{\text{RCV Buffer Size}}{\text{Round Trip Time (RTT)}} \qquad (3)$$

Therefore,

$$\text{Throughput} \leq \frac{\text{RWIN (TCP Receive Window)}}{\text{RTT}} \qquad (4)$$

Equations 1 to 4 above were also used to compute the throughput of the network after measurement and the results obtained were the same as those obtained with NetStress and Jperf, this was used to determine the accuracy of the software.

The settings of the access point (Wireless Router) have been configured and the network sniffer was used to measure the network throughput and the graph of throughput is plotted against the number of work station in Microsoft Excel as shown in figure 1.

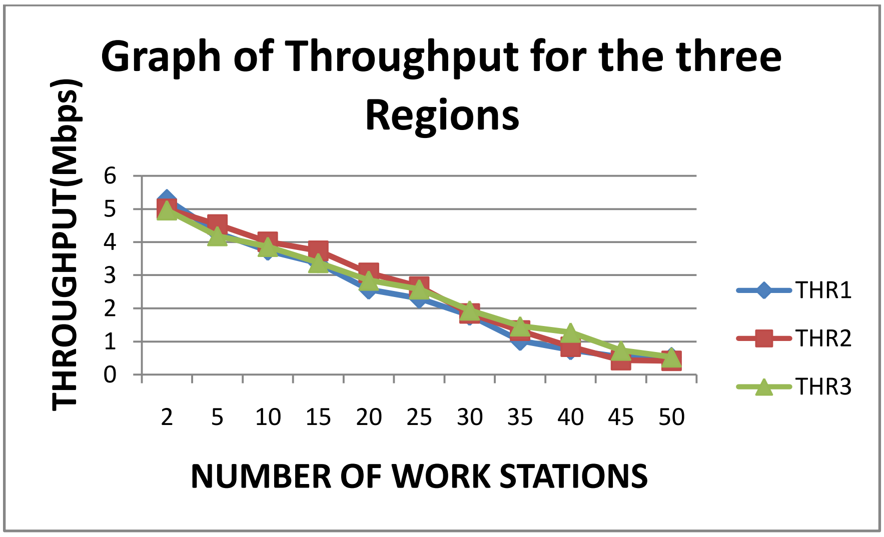
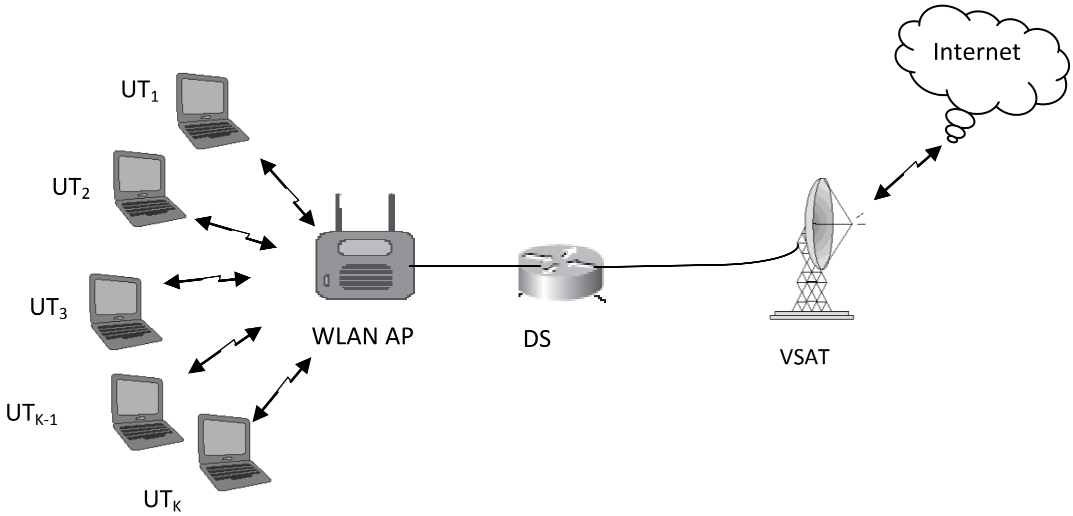


Figure 1: Graph of Throughput against Number of work stations in the three regions

2. Real Time Measurement Analysis

When the software(s) were used to measure throughput on the network, the results reported a throughput of approximately 694,030 to 54,920 bytes- per-second. So, how does this compare with the theoretical maximum of 11 Mbps? 11 Mbps is equivalent to 1,441,792 bytes-per-second (11 x 1024 x 1024 bits / 8 bits / byte). So, is our actual throughput (which is roughly 48% to 3.8% of the theoretical) reasonable? The short answer -- yes. The 11 Mbps is the theoretical maximum of what the hardware and medium are capable of. There are numerous factors that can contribute to the difference, including network traffic, interference from other wireless devices and, equally important, the overhead of the 802.11 and TCP protocols. The throughput measured doesn't take into account that every 802.11 packet includes additional bytes besides the data payload.
This graph, at minimum number of stations and low traffic, the throughput is significantly good, but as the number of workstation increases, the throughput depreciate.



Key: Wkstn- Workstation, WLAN AP- Wireless LAN Access Point, VSAT- Very small Aperture Terminal

Figure 2: Adopted Typical WLAN Architecture

3. Development of Matlab Model

This section presents the queuing model of WLAN APs for IEEE 802.11b.The adopted typical WLAN architecture was depicted, and the mode of operation of CSMA/CA, also known as the basic access mechanism which is implemented at the WLAN Access Point, was presented**.** Conversely, a comprehensive Model of WLAN MAC DCF which is based on the adopted WLAN architecture for the determination of enhanced WLAN performance under saturated traffic loading on WLAN was also depicted. The model design for IEEE 802.11b DCF was built over MATLAB Simulink environment, simulated and analyzed to establish the sort for enhanced performance.

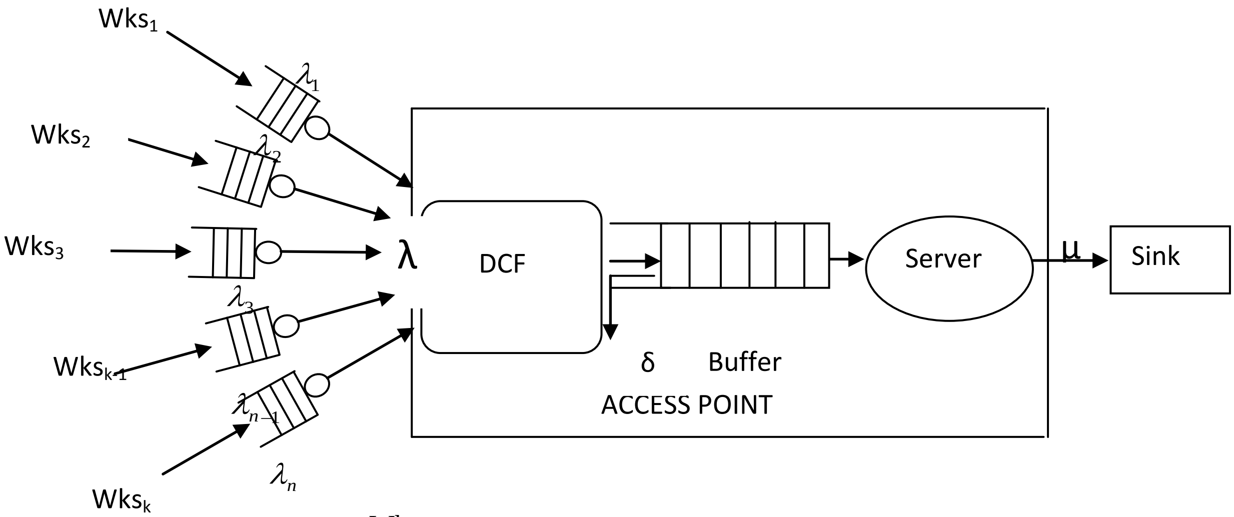
4. The Adopted Typical WLAN Architecture

This thesis focuses on the principles of Basic Access mechanism (CSMA/CA). The IEEE 802.11 architecture comprises several components such as workstations, the WLAN Access Point (WLAN AP), Distribution System (DS), Server and Very Small Aperture Terminal (VSAT) and services that interact to provide wireless communication to stations which are any devices that incorporates the functionality of the IEEE 802.11b protocol and can connect to the wireless media.

5. Network Model

The performance of a WLAN may be defined by the QoS parameters. The key QoS parameters considered in the modeling of the WLAN for enhanced performance at network saturation are packet delay, packet arrival rate, packet loss rate and throughput etc. These QoS parameters influence the operation of the network and specifically the resource assignment to the traffic load. A station that is ready to transmit packets generates a random number, calculates its exponential value of the back-off counter and keeps decreasing the value of its back-off counter after the air medium was sensed to be idle. Other parameters considered are the contention window, the number of workstation stations, the service rate and the number of attempts.

The network model was based on an isolated IEEE 802.11b MAC DCF protocol of the network architecture which operates on the principles of CSMA/CA. The figure 3.4 represents the network model.



Where,

λ = arrival rate,

µ = service rate

$$\lambda >> \mu$$

$$\lambda = \sum_{i=1}^{n} \lambda_i$$

Figure 3: Model of WLAN Access Point

The WLAN model was defined to simply consist of workstations (traffic source generators and sinks), MAC DCF communication (CSMA/CA) protocol, single server and a buffer system. The source generators were intended to generate different types of packet (for example, background traffic, best effort traffic, video traffic, and voice traffic) with varied length randomly. The source generators were developed on the basis that packet arrival process is randomly distributed and Poisson in nature with intensity. The source generators have parameters such as arrival rate, retransmission, binary exponential back off counter and packet length. Also, random exponentially distributed packets lengths were implemented at the WLAN access point. The rate of packet transmission through the wireless medium was represented by µ (bps).

The MAC DCF communication protocol was employed in the simulation modeling in order to ensure that the arriving traffic has equal probability of being served in a random manner. The server utilization was enhanced by the application of buffering system that controls packet arrivals from the sources. The workstations use random back-off procedure to avoid probability of two or more workstations accessing the channel at the same time.

The sink terminates packets transmitted from the source generators via the single server. The sink has stop time attached to it. The stop time gives the delay or time elapsed of the packets transmitted.

Probes were strategically implemented in the model to gather the necessary information (data) on the desired quality of service (QoS) parameters. In other words, the WLAN QoS parameters such as throughput, packet loss rate and packet delay are also probed and they can be displayed numerically.

6. Modeling Assumptions and Simulation

A simulation model has been developed using MATLAB Simulink (figure 4) to study the network throughput performance of the IEEE 802.11b DCF protocol. To simplify the simulation model, a perfect radio propagation environment was considered in which there is no transmission error due to interference and noise on the system, and no hidden and exposed station problems. The following assumptions were made regarding the data traffic:

1) No hidden stations are considered.
2) The network consists of a finite number of stations, *n*.
3) Each station always immediately has a packet available for transmission (saturation conditions).
4) Packet Generation**:** Streams of data packets arriving at stations are modeled as independent Poisson processes with an aggregate mean packet generating rate » packets/s.
5) Packet Size: Packets are of fixed length. The time axis is divided into slots of equal length, and the transmission of one packet takes one slot time.
6) Buffer size: The access point and stations in the network has a large buffer, modeled as a buffer of infinite size, to store packets. This assumption means that packets cannot be lost due to a buffer overflow when the system is under manageable input loads.
7) Destination addresses: It was assumed that packet arrives at a station are uniformly destined to $N - 1$ other station in the network.

The parameter values were used in the simulation are shown in table 1 and 2. The simulation was run for 60 seconds in other to achieve the required stability during which throughput were computed for varying number of workstations and network resources. The workstations generate packets with gamma or exponential or geometric time distribution; the gamma/exponential/geometric parameter has 0.15 mean values. Network loading was varied from 10 to 100 workstations. The workstations have a finite buffer capacity while the transmission rate was varied from 1Mbps to 11Mbps.

Table 1: Mapping between user priorities and Access Categories (ACs)

User Priorities	ACS	Destination	CWmin	CWmax
1	AC_BK	Background	aCWmin=15	aCWmax=1023
0	AC_BE	Best Effort	aCWmin=15	aCWmax=1023
2	AC_VI	Video	(aCWmin+1)/2-1=7	aCWmin=15
3	AC_VO	Voice	(aCWmin+1)/4-1=3	(aCWmin+1)/2-1=7

Table 2: Parameters used in simulation and calculations

Parameters	Values
Data rates	1, 2, 5.5, 11 Mbps
SIFS	10 μsec
DIFS	50 μsec
Slot time	20 μsec
Packet Size	1500 bytes
Traffic distribution	Gamma, Exponential and Geometric.
PHY modulation	DSSS
CWmin	31
CWmax	1023
Simulation Time	60 Seconds

Saturated traffic condition means that all stations on the access point always have a packet available for transmission. Throughput under saturated traffic situation is the upper limit of the throughput achieved by the system, and it represents the maximum load the system can carry in the stable condition. The Matlab model is as shown in figure 4 below.

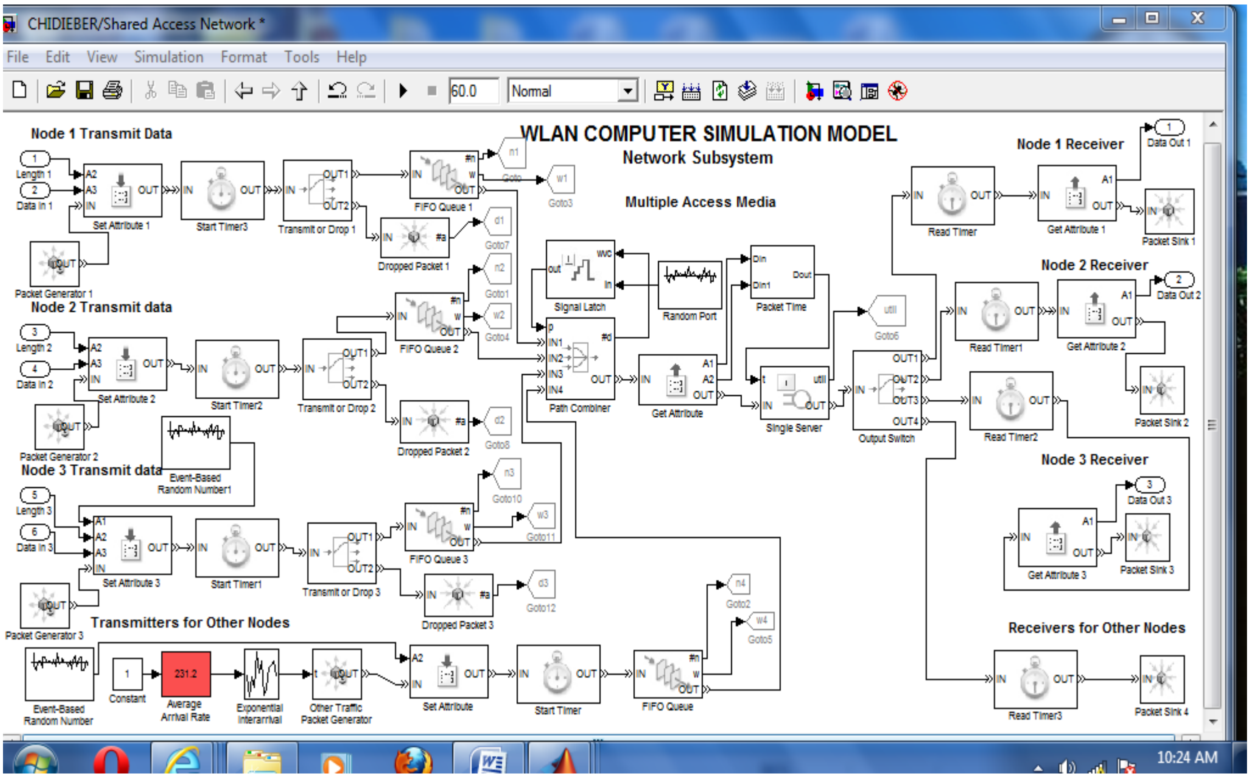


Figure 4: WLAN Computer Simulation Model

When the above model simulated, the WLAN throughput reading were recorded, the graph of throughout is plotted against the number of work stations in Microsoft Excel. The graphs of the three traffic distribution were plotted as show in figures 3 to 6.

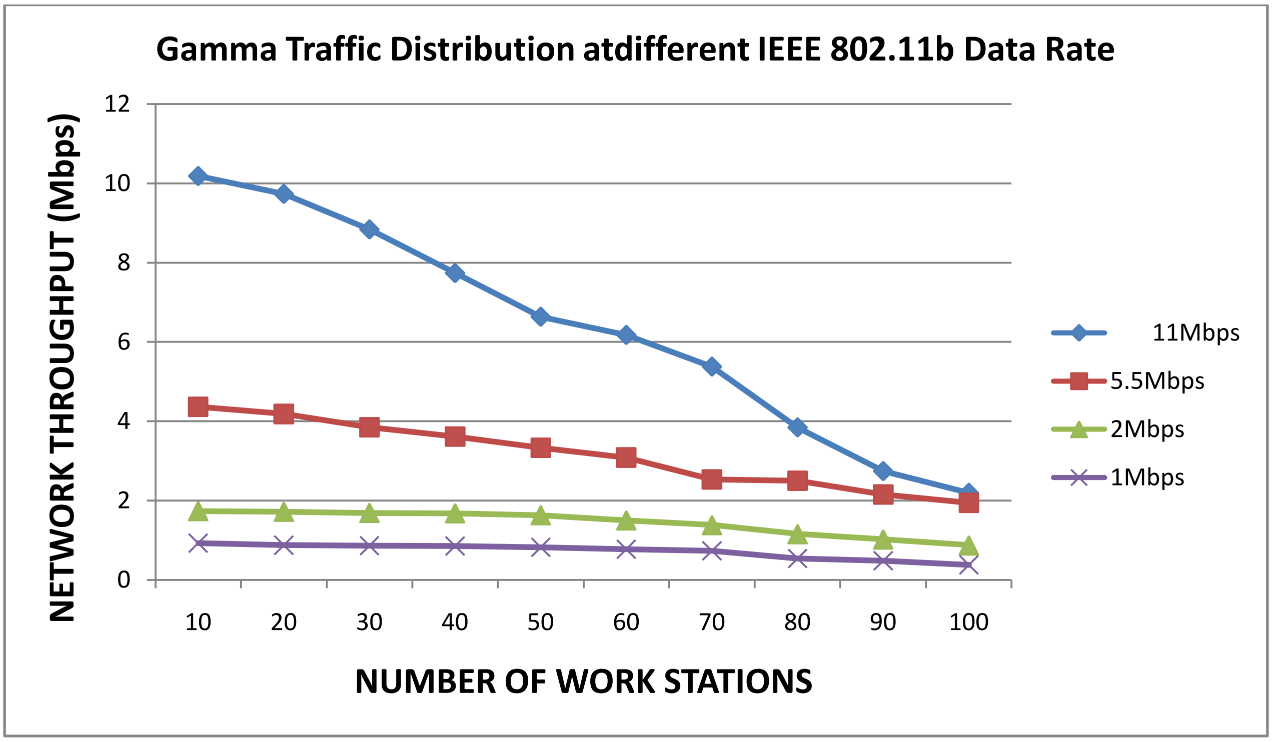


Figure 5: Graph of Mean Throughput against Number of workstations using Gamma traffic distribution

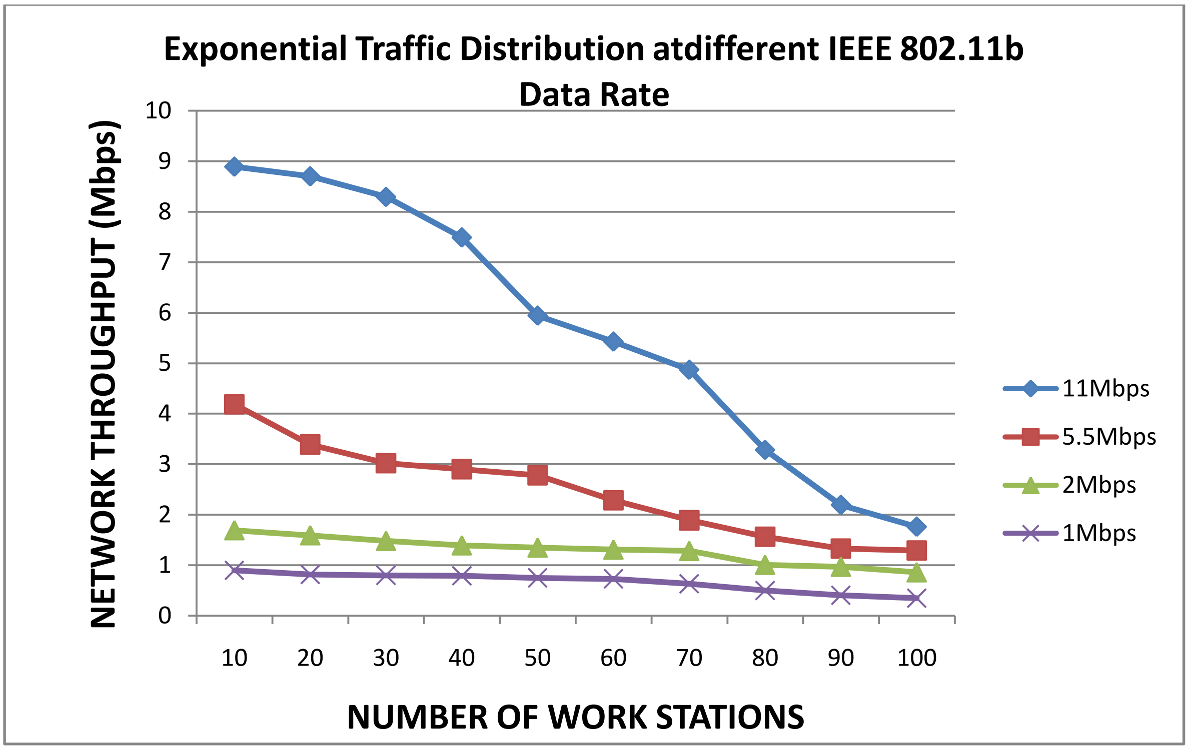


Figure 6: Graph of Mean Throughput against Number of workstations using Exponential traffic distribution

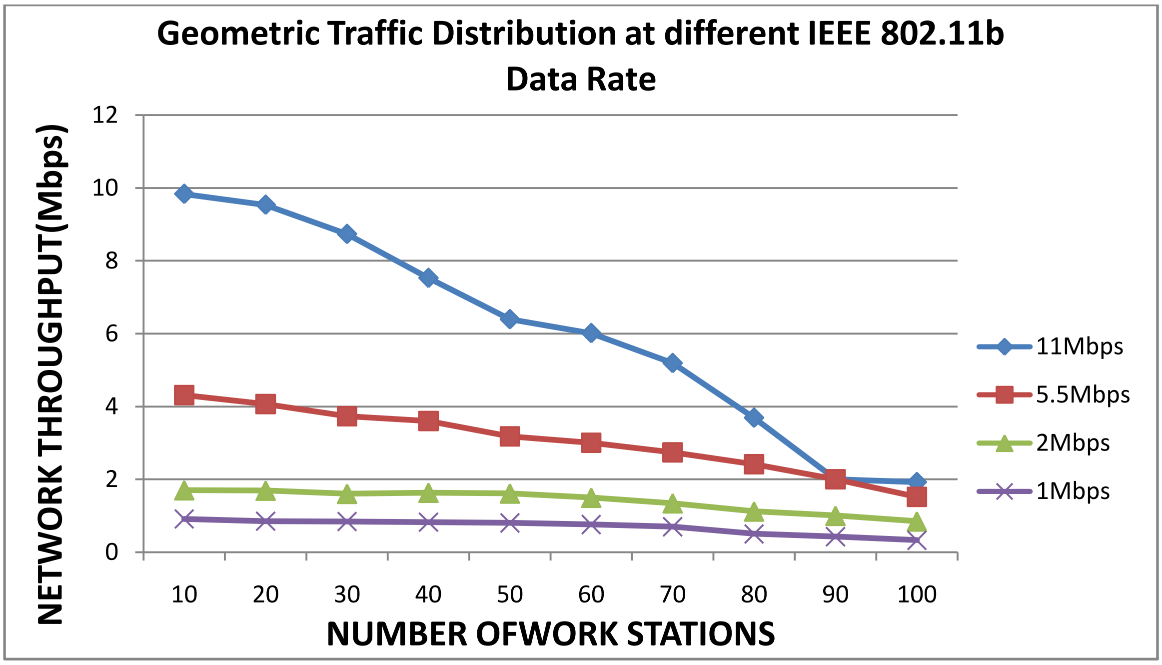


Figure 7: Graph of Mean Throughput against Number of workstations using Geometric traffic distribution

7. Throughput Results Analysis

The result of the three traffic distributions shows that Gamma traffic distribution has the best performance whereas Exponential traffic distribution has the least performance. In radio communication networks, throughput or network throughput is defined as the average rate of successful message delivery over a communication channel.

Bandwidth offered by an Access Point is shared among all STA's within its coverage area. Throughput of an Access Point increases in proportion to the amount of traffic load added by all connected STA's provided that the overall traffic load does not exceed the capacity (bandwidth) of the AP. When AP's workload exceeds or approaches its capacity, the throughput does not increase further. This phenomenon is called channel Saturation or congestion. In general, a highly overloaded AP may simply reject new association requests. If an AP is not overloaded then it grants association request from STA's based on work-load status. The request can be granted only when the predicted load level after the association does not exceed some predefined threshold. Throughput also depends on control message overhead and congestion. As the control message overhead and collision increases, overall throughput will be decreased. A simple way to increase overall system throughput is to deploy additional APs covering the same region, in anticipation that heavy traffic load can be distributed among multiple APs. Unfortunately, as each STA independently selects an AP to camp on, STA's may be associated with few APs while other APs remain idle. Consequently, the traffic load is not fairly shared by APs. This problem motivates load-balancing protocols for IEEE 802.11 networks.

Since the IEEE 802.11b standard specifies various data rates, it is interesting to study how the throughput is affected by the medium data rate. Figure 5 to 7 presents the proposed model simulation results of IEEE 802.11b DCF by plotting the throughput against number of workstations for four different data rates (C =1, 2, 5.5 and 11 Mbps) for basic access mechanisms.

In Figures 4 to 7, the graphs of network throughput versus number of workstations for infrastructure networks were plotted. Considering the Gamma traffic distribution, which has the best performance and slightly different behaviour from the three distributions, it showed that throughput is higher and increases with continous increase in data rate but decreases slightly with increase in the number of workstations from 10 to 80 workstations at 1, 2, 5.5, 11 Mbps data rate. In order words, it was observed that the network throughput decreases as the number of active stations increases for N = 10 to 80 stations (at 80% offered load). Under the infrastructure network, the throughput is saturated at around $N \geq 80$ stations. Now let us examine the maximum and minimum throughput of the IEEE 802.11b. As seen in Figure 5, the maximum achievable throughput is 10.182 Mbps for N = 10 station. This throughput is approximately 93% of the maximum theoretical bandwidth of 11 Mbps. The minimum throughput under the infrastructure network is 2.191 Mbps which is around 20% of the maximum bandwidth of 11 Mbps for N= 100 stations (at 100% offered load). These graphs illustrates that the throughput performance strongly depends on the number of the stations for all data rates when basic access mechanism is employed. On the other hand, if basic access is used, the throughput decreases as the number of the stations increases. Moreover, the throughput is reduced when the data rate increases. The situation is explained by considering that the time spent for frame transmission is decreased as the data rate increases but the time overhead spent on DIFS, SIFS and the back off delay remains the same.

8. Model Validation

Comparing the proposed model simulation result and field work result of IEEE 802.11b DCF by plotting the Network throughput against number of workstations at 11Mbps packet data rate, at minimum number of work stations/low traffic, the proposed model has a significant better throughput performance.

For the model validation, the proposed model simulation results with the experimental throughput and delay results collated via the two network sniffers for IEEE 802.11b DCF was compared. A close match between MATLAB simulation results and the experimental results validates the model.

9. **Conclusion and Recommendation**

The objective of this research is to carry out a performance analysis of IEEE 802.11b medium access control distributed co-ordination function (MAC DCF) traffic loading, under saturated network, by investigating the effect of traffic distribution on the quality of service parameter on WLAN, in other to establish enhanced WLAN Performance. This research has presented a traffic loading for MAC DCF which supports WLAN's QoS Parameters. Using the proposed model, evaluation of the network throughput performance of IEEE802.11b DCF for basic access mechanism under network saturation condition using MATLAB. The basic access mechanism is a key feature of the IEEE 802.11b standard that uses virtual carrier sensing and random back off procedure to avoid the probability of two or more station from accessing the channel at the same time, thus, causing collision.

To realize this feature, the WLAN MAC architecture design was organized, modeled, and implemented in the Simevent within the MATLAB Simulink framework, in an organized manner following the software engineering best practices.

In this work, results showed that the IEEE 802.11b does not perform well in terms of high throughput at high traffic load conditions. For example, if the number of workstations increases, throughput performance of the IEEE 802.11b protocol degrades significantly. Therefore, to achieve a better enhanced network performance, it was observed that the IEEE 802.11b WLAN requires an improvement on its window back off algorithm and fairness.

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