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PERFORMANCE ANALYSIS OF WIRELESS LANs USING DISTRIBUTED COORDINATED FUNCTION

Varun Singh^{*1}, Uttam Nath²

^{*1}Department of CSE, Manipal Institute of Technology, Manipal, Karnataka, India
varun.singh1120@outlook.com¹

²Department of CSE, Tezpur University, Naogaon, Assam, India
mon1.nath@gmail.com²

Abstract: Wireless networks running in infrastructure mode use one or more WAPs (Wireless Access Points) to connect the wireless network nodes to a wired network segment. A single WAP servicing a given area is called a Basic Service Set (BSS). This service area can be extended by adding more WAPs. This is called, appropriately, an extended basic Service Set (EBSS). All the registered nodes and relaying traffic in the network is controlled by the Wireless Access Points (henceforth referred to as Access Points or AP). Though all the traffic in the network is routed through AP, the open nature of the underlying medium is prone to environmental factors, etc. which degrade the performance of overall network. However, in a saturated case AP becomes the point of dispute among the nodes which can result in collisions, packet drops etc.

In this paper, the authors have analysed the performance of 802.11 wireless local area networks that utilizes the Distributed Coordination Function (DCF). A simulation study having contending stations within the transmission range of an AP in a saturated environment are considered, in view of varying data rates and packet sizes in an error free environment. Simulation results are presented and analysed in the end

INTRODUCTION

A wireless LAN (WLAN or WiFi) is a data transmission system designed to provide location-independent network access between computing devices by using radio waves rather than a cable infrastructure. In the corporate enterprise, wireless LANs are usually implemented as the final link between the existing wired network and a group of client computers, giving these users wireless access to the full resources and services of the corporate network across a building or campus setting. The widespread acceptance of WLANs depends on industry standardization to ensure product compatibility and reliability among the various manufacturers. The 802.11 specification [IEEE Std 802.11 (ISO/IEC 8802-11: 1999)] as a standard for wireless LANs was ratified by the Institute of Electrical and Electronics Engineers (IEEE) in the year 1997. This version of 802.11 provides for 1 Mbps and 2 Mbps data rates and a set of fundamental signaling methods and other services. Like all IEEE 802 standards, the 802.11 standards focus on the bottom two levels the ISO model, the physical layer and link layer. Any LAN application, network operating system, protocol, including TCP/IP and Novell NetWare, will run on an 802.11-compliant WLAN as easily as they run over Ethernet.

In spite of having too many advantages, wireless networks suffer from some limitations also which are mostly due to the underlying medium being used. A few of them are mobility, fewer battery life, frequent collisions and limited bandwidth. The factors mentioned previously lower the overall throughput of the wireless networks [1]. A lot of research has been done to elevate the performance by proposing numerous models which emphasize on increased

throughput and decreased delay. However, only few of them have been successful, others lacking at one place or the other.

The analysis of 802.11 CSMA/CA was first conducted by [2] to calculate the throughput in a saturated environment. After this, numerous advancements have been proposed in this area like Markov Chain model to incorporate retransmission without using the backoff process [3], to minimize the complexity and computation time the Markov chain model is reduced from two dimensions to one [4], etc. Another variation has been the calculation of packet drops probability, delay, etc. to analyze CSMA/CA based wireless network's performance. But generally, the non-saturated cases are considered to emphasize on one parameter at a time.

In this presented study, the authors have investigated the performance of a wireless network by varying data rates and achieved throughput, to extract the most suitable parameters for an infrastructure based wireless network in a saturated environment. The rest of the paper is organized as follows. Section II provides preliminaries and overview of some of the related concepts. Implementation details are discussed in section III. Simulation results and analysis are presented in section IV. Lastly, section V concludes the paper with the derived conclusion of this study and stating the future research directions.

PRELIMINARIES

A. IEEE 802.11

IEEE 802.11 is the generic name of a family of standards for wireless networking related to Wi-Fi. The numbering system for 802.11 comes from the IEEE, who uses "802" to designate many computer networking standards including Ethernet (802.3). 802.11 standards define rules for communication on wireless local area networks (WLANs). Popular 802.11 standards include 802.11a, 802.11g, and 802.11n. 802.11 (with no letter suffix) was the original standard in this family, ratified in 1997. 802.11 defined WLANs that operate at 1-2 Mbps. This standard is obsolete today. Each extension to the original 802.11 appends a unique letter to the end of the name. While 802.11g and 802.11n are the most interesting to the average consumer, many other extensions exist or are under development.

TABLE 1: SUMMARY OF STANDARDS IN 802.11 FAMILIES [13]

Protocol	Release Date	Op.Frequency (GHz.)	Data Rate (Typical)	Data Rate (Max)
Legacy	1997	2.4-.25	1 Mbit/s	2 Mbit/s
802.11a	1999	5.1-5.35/5.47-5.725/5.725-5.875	25 Mbit/s	54 Mbit/s
802.11b	1999	2.4-.25	6.5Mbit/s	11 Mbit/s
802.11g	2003	2.4-2.5	25 Mbit/s	54 Mbit/s
802.11n	2006 (draft)	2.4 GHz or 5	200 Mbit/s	540Mbit/s

A summary of the above discussed amendments is shown in table-1.

B. Independent & Infrastructure Basic Service Set

The basic building block of the WLAN network is the 802.11 basic service set (BSS). A BSS defines a coverage area where all stations within the BSS remain fully connected. There are two BSS network topologies Infrastructure BSS Networks & Independent BSS (IBSS) Networks.

In Independent BSS topology, all stations within the BSS communicate directly with each other. In this situation, one station creates, or starts, the BSS network and other stations join the BSS network. IBSS networks, which are also known as "ad hoc" networks, provide limited support for 802.11 authentication, authorization, and privacy services for the BSS network.

In Infrastructure BSS topology, all stations within the BSS communicate with each other through an access point (AP). In this situation, the AP establishes the BSS network. In

addition, an infrastructure BSS can consist of more than one interconnected APs that establishes an extended service set (ESS) network. Each AP within the BSS network provides 802.11 authentication and authorization services for access to the BSS network, as well as privacy services for the encryption of data sent through the BSS network. In addition, each AP can act as a bridge between the wireless and wired LANs, allowing stations on either LAN to communicate with each other.

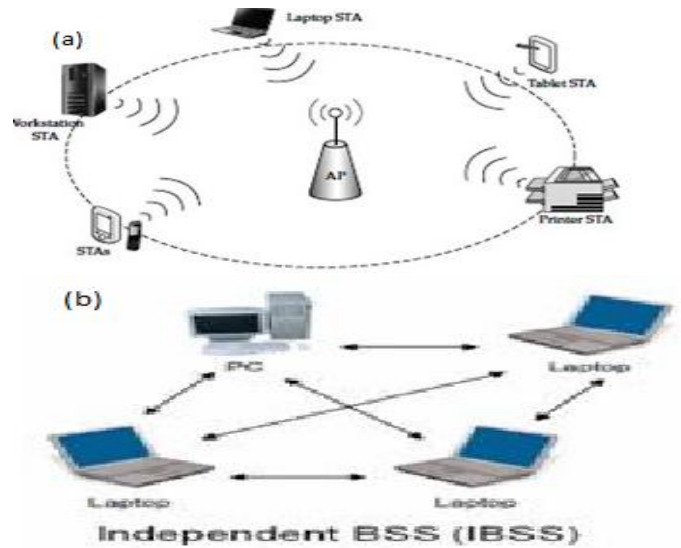


Figure 1: (a) Infrastructure and (b) Independent BSS Architecture

C. Distributed Coordination Function (DCF) [14]

IEEE 802.11 MAC provides distributed access along with optional centralized access to the medium, as shown in Figure-2. The distributed access control mechanism is called distributed coordination function (DCF) which is a random access scheme and depends upon the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [2]. As described in [5], in DCF before attempting to transmit data on the medium the station initially ensures that the medium is idle. A random back-off interval is selected by DCF, which is less than or equal to the current contention window (CW) size based on the uniform distribution. When the medium is idle this back-off timer is decreased by one at every time slot, and it might have to wait for DIFS (DCF Inter-Frame space) following a successful transmission or EIFS in case of collision. If the medium is busy then the station will have to suspend its back-off timer until the transmission ends and the medium becomes idle. The station will transmit only when its back-off timer reaches zero. If there is a problem with the transmission, like it fails to reach or there is a collision, the station will invoke back-off procedure. To begin the back-off procedure first the size of contention window (CW) is initialized with the initial value of CW_{min} , then this value is doubled till it reaches the maximum upper limit of CW, i.e. CW_{max} . This value of CW_{max} will be kept until it is reset. After this the station will set its back-off timer to a uniformly distributed random number in between interval of $[0, CW]$ and then the station will retransmit when back-off timer reaches to zero. This procedure for retransmission will occur every time until the transmission is successful or transmission failure limit

reaches its maximum value resulting in discarding of the packet, the value of CW will be reset to CW_{min} [6, 7].

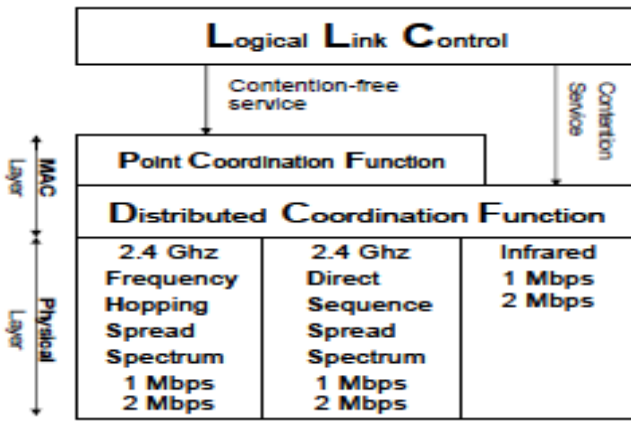


Figure-2: Protocol Layers' Architecture of Simple IEEE 802.11

D. Exponential Back-off Algorithm

A packet transmitted first time has its CW set to CW_{min} . After every collision the value of CW is doubled till it reaches CW_{max} . This process is called exponential back-off. The value of CW is not of fixed size because when station experiences a collision it has no idea that how many stations are involved collision. CW will be small if few numbers of packets collide then it will appropriate to choose random back-off time from a small set of small values. But CW will be long if large numbers of packets collide then there will a large set of values to choose a value for back-off timer [5, 8].

See equation (1) below:

$$Back - off\ Timer = INT (CW * Random ()) * SlotTime \quad (1)$$

where;

CW, is an integer between CW_{min} and CW_{max}

Random (), is a random number generator

INT, is an integer function

If the set of values is small then choice to choose value for back-off timer will be limited. And if several STAs choose value from that set for back-off time then the probability of choosing same value will be high causing more collisions. To reduce the collision probability, time slots are defined in a way that STAs can determine that if another STA has started to transmit at the beginning of the previous time slot, then the risk time will be equal to time taken for packet transmission [9, 10]. But if STAs are not capable to sense this, then the risk time will be double of packet transmission time. If STA has a packet to transmit and the medium remains idle longer than DIFS then this back-off algorithm is not used.

E. DCF Throughput Analysis:

The system throughput S can be defined as the fraction of time the channel is used to successfully transmit payload bits. If α is the back-off slot time per data frame transmission period, the time slot size will be equal to α . Then the frame transmission period will be considered as the

unit time and all other time intervals are normalized to this time unit. In order to explain this for finite number of stations, we assume that the system state alternates between two periods: Idle periods I, when stations have no frame to transmit and second is busy periods B i.e. when at least one station transmits frame. Let U be the time for useful transmission. If $E[X]$ denotes the expectation of a random variable X, then the system throughput S, as shown in equation (2) can be stated as:

$$S = \frac{E(U)}{E(B) + E(I)} \quad (2)$$

Equivalently, expresses the throughput as

$$S = \frac{E[Payload\ transmitted\ in\ a\ slot]}{E[Length\ of\ a\ slot\ time]} \quad (3)$$

When calculating the throughput, essential parameters are the durations when the medium becomes busy, because of successful transmission and unsuccessful transmission. As shown in Figure-3, durations of successful T_{succ} and unsuccessful T_{col} transmissions for Basic access methods is:

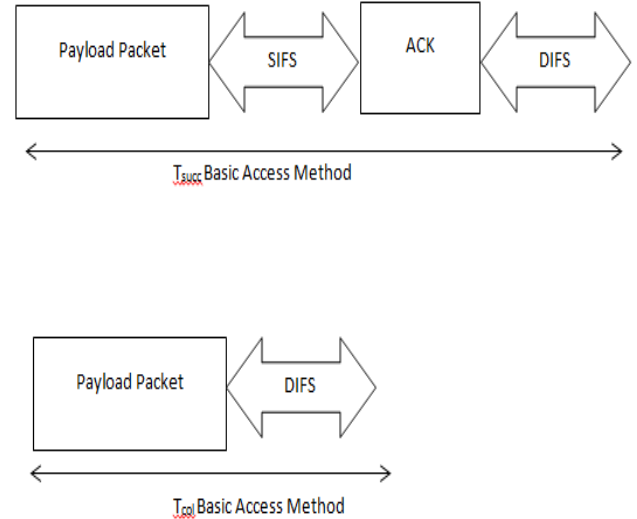


Figure-3: T_{succ} & T_{col} for Basic

IMPLEMENTATION DETAILS

For this paper, the simulation is setup to analyze the performance of an infrastructure based wireless LAN. For simplicity it is considered that there is only one Basic Service Set (BSS) comprising of an Access Point (AP), which acts as a base station, and comprising of multiple number of nodes ranging in-between 1 to 40. Furthermore, it is also assumed that the nodes are in saturated mode i.e. every node has data to transmit all the time. This simulation will be utilizing Destination Sequenced Distance Vector (DSDV) as underlying network routing protocol and traffic

will be generated with Constant Bit Rate (CBR) traffic source with data rate of 5.5 Mbps and 11 Mbps (depending on the scenarios explained in next section). As there are two access methods of DCF to access the medium; Basic and RTS/CTS Access Method. This simulation will only be implementing Basic Access Method because both the RTS/CTS and Basic access method give the same results in case of a single BSS because there will be no hidden nodes.

A. Factors Effecting Simulation

Many factors can affect the results of the simulation. A few of those factors are Simulation Runtime, Packet Size, Data Rate, and Radio Propagation Model. Below is the list of the factors affecting the simulation and how they are handled in the simulation:

Simulation Runtime: Not much of difference with this factor as we can see that there is not much difference between long runtime and less runtime of the simulation. The only thing to look after is that simulation should not be run for very less time as this can make the results unreliable because the starting time of the simulation (approx. 2-5 sec) is warm-up time as in that time it initializes the connection and then after initializing the connections the simulation enters the steady state in which the results taken are more reliable.

Packet Size: Transport layer rely on checksum in the packets for integrity. If erroneous bits are found in packets those packets are discarded. With this in mind, in simulation, we considered long and small packets. With the long packets it was observed that the rate of packet dropping was quite high which might be due to bit errors. Also long packets get divided into more fragments which cause delay in transmission. In case of small packet size, we observed higher proportional protocol header overhead.

To deal with packet size factor affecting the simulation two different sizes of packet size i.e. 512Kb and 1024Kb are used. These packets will provide reliable results as by using long or small packet sizes unreliable results in the simulation were observed.

Data Rate: in IEEE 802.11b DCF, each competing node is given approximately equal opportunity for transmitting packets irrespective of time required to transmit a packet. So in this case if in a wireless network data rate and channel conditions are similar for each node and nodes have different packet sizes then the throughput and delay will be nearly same. For example if one node is transmitting at 1 Mbps and other node is transmitting at 11 Mbps. As in the case of node transmitting at 1 Mbps the time taken to transmit a frame will be longer as compared to the node transmitting at 11 Mbps, but the channel mostly will be used by the slower node. Hence the total throughput of both the nodes will be nearly same. In case of this project, IEEE 802.11b support two different data rates i.e. 5.5 Mbps and 11 Mbps.

Simulation will be implementing both data rates to analyze both throughput and delay.

Radio Propagation Model: There are different radio propagation models, which can be implemented in NS-2 to simulate IEEE 802.11b channel. In the simulation implemented, it is considered to have an open environment and range of nodes up to 100 meters, for implementing this Two Ray Ground model is used to implement in NS-2.

B. Analyzing Traffic

In this simulation, NS-2 generates new trace file format which is further utilized by the AWK script for calculating the Average Throughput and Delay for the current simulation scenario. As implemented in simulation AWK script calculates average throughput as follows.

$$Avg. Throughput [Mbps] = \frac{recvSize}{stopTime - startTime} \times \frac{8}{100000} \quad (4)$$

Here recvSize is the total received packets' size, stopTime is the time when simulation ends and startTime is the starting time of the simulation. 8/1000000 is used to convert the throughput from bytes/second to Mbps. To calculate average delay, the script computes the time difference between the receive time and the send time for each packet and then divide the delay with the number of packets received to get average delay, as follow:

$$Delay = Delay + (recvTime[i] - sendTime[i])$$

$$Avg.Delay[s] = Delay / recvNum \quad (5)$$

Here 'i' represent the current packet. recvTime and sendTime denotes receiving and sending time of the current 'i' packet. recvNum is the total number of received. The delay computed is in seconds which is then converted to milliseconds

C. Simulation Scenarios

This simulation is conducted in NS-2 network simulator [11, 12] and will comprise of two scenarios to understand the effect of packet size and data rate on performance of a simple wireless network. In simulation we will be having one BSS, error free channel and static configuration of nodes, so that all nodes are connected to base station. In BSS number of nodes will vary from 10 to 30.

The simulation will run for 15 seconds and all nodes are in saturated state i.e. they have packets to transmit all the time during the simulation running time. To makes nodes saturated we have used CBR traffic generator which implements Poisson Arrival process of frames for transmission. And the nodes are modified to transmit data at a radius of 100m, to make this possible the transmission power of nodes is set to 281.8mW. The details provided above will be common for both scenarios discussed as follows:

Scenario 1: In this scenario the data rate will be kept constant, 11 Mbps, but packet size will vary i.e. 512 Kb or 1024 Kb. Throughput and Delay will be recorded for both packet sizes, against the increasing number of nodes.

Scenario 2: This scenario will be involving fixed packet size of 512 Kb. But in this scenario two different data rates will be utilized i.e. 5.5 Mbps or 11 Mbps. Number of nodes will be increasing same as that in Scenario 1, and throughput and delay will be recorded for both data rates.

RESULTS & DISCUSSION

We executed the simulation for all use cases and compiled the results in the following section. Both the network performance (throughput) and network delay is calculated by implementing scenarios in the simulation.

A. Throughput:

In the DCF mode, with basic access method, the overhead of throughput is caused by the collisions and contention when the number of nodes in the wireless network increases, Figure-4 shows throughput when the data rate is kept same and the packet size is changed.

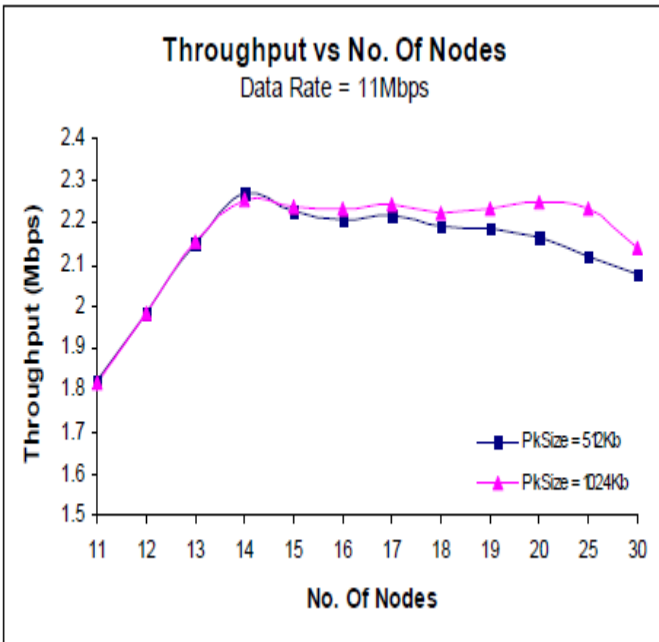


Figure-4: Throughput: Different Packet Sizes

From the graph we can see that the throughput stays almost same till some number of nodes for both 512kb and 1024kb packet sizes. As we increase the number of nodes, in turn the throughput increases a little bit for bigger packet. It's because the simulation uses error free channel and the bigger packet increases efficiency of the channel. Actually the previous assumption of error free channel is not practical because actually the channel is not error free and we may see channel fading due to obstacles. Because of this the throughput decreases with large packet size.

For small packet size, throughput is quite low. It's because with small packets, transmission will complete quickly and this makes the availability of channel abrupt. This causes the participating nodes to try to acquire the channel thereby increasing contention resulting in low throughput.

Now if we keep the packet size same and vary the data rate. From Figure-5 we can clearly conclude that with high data rate, we get high throughput. It's because with high data rate if number of nodes increase, this increases the utilization of the channel which in turn increases throughput. On the other hand, with low data rate, the throughput is lower as compared to high data rate. It's because with low data rate and high number of nodes, the frequency of packets getting dropped will be more. Result, drop in

throughput which is caused because of increased waiting time of nodes.

B. Delay:

As discussed above, the effect of packet size and data rate on the throughput of the wireless network simulated. There is another factor which is critical while analyzing the performance of a network, known as delay. The figure 5 below represents the effect on delay when we have fixed data rate but variable packet size.

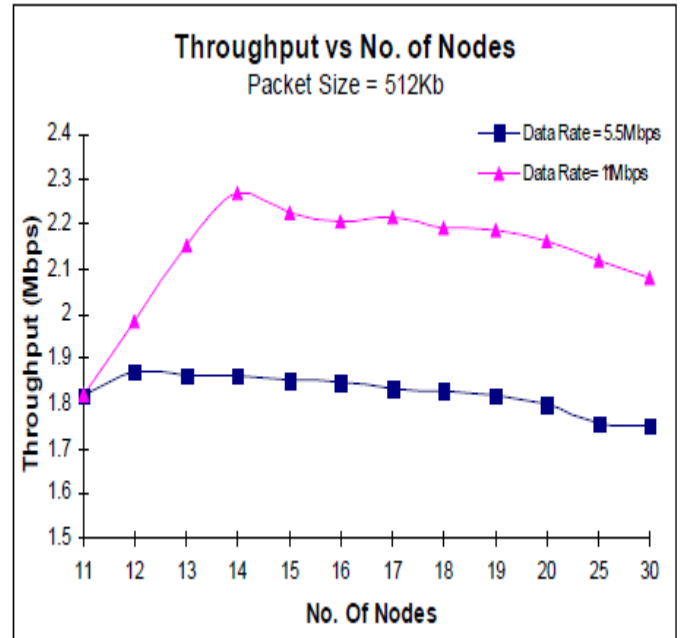


Figure-5: Throughput: Different Data Rates

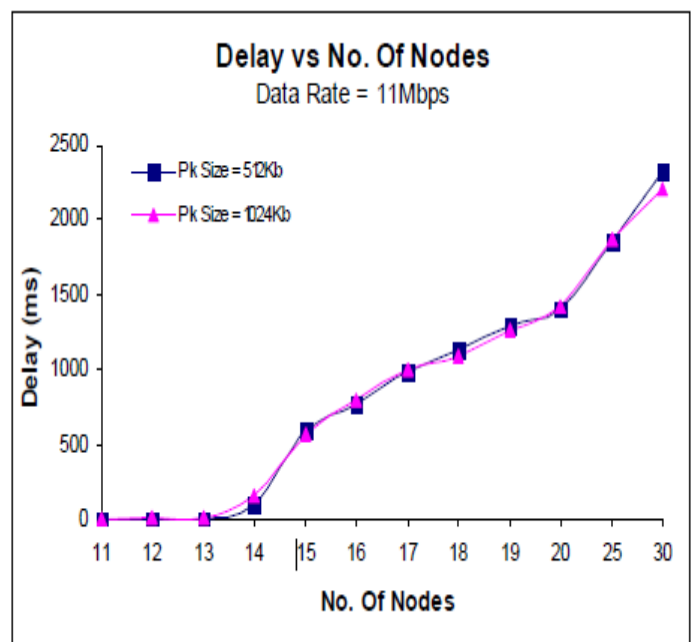


Figure-6 Delay: Different Packet Size

In Figure-6, we can conclude that the variation of delay does not depend much on packet size. It is because when we send smaller packet, the transmission rate will be high and so will

be the contention of channel which will cause delay. Meanwhile in case of large packets, transmission time for the packets will be high causing more waiting by the contending nodes to access the channel and might also cause more packet dropping.

Figure-7 shows the graph for delay plotted against the number of nodes, with same packet size but different data rates.

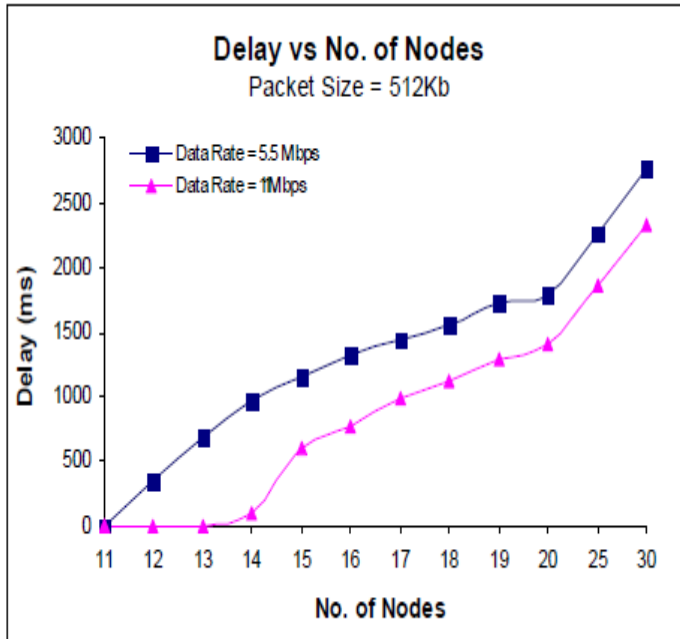


Figure-7 Delay: Different Data Rates

From the above graph we can see that as we increase number of nodes with low data rate, the delay increases very rapidly. The reason for this is time to transmit data packets is high when data rate is low which keeps the channel busy and other nodes wait till the transmission is complete. On the other hand, with high data rate, the frequency of packet transmission will be high making the channel available thereby reducing the delay. But a time comes when the number of nodes which are transmitting the packets is high, which will increase the collision and increased waiting time of the contending nodes. So it is safe to assume that we should use high data rate, irrespective of packet size, to have less delay in network.

CONCLUSION

In this paper, we have presented a simulation for calculating the throughput and delay in performance of IEEE 802.11b using Distributed Coordinated function. For the course of simulation, we have assumed that a few number of saturated stations transmit packets in ideal channel and use Basic Access method to acquire channel for transmission in a single BSS. The results obtained from the simulation are validated by comparing results with analytical and other simulations.

Also we have seen that the performance of the Basic Access Method depends upon the number of nodes in wireless network. It is also evaluated that by using small packet size the contention for channel between the stations becomes higher causing high delay and if small packets are

transmitted upon low data rate the bandwidth overhead results in reduction in the throughput. However, on the other hand by having longer or small packet size and high data rate with large number of nodes, results in more channel utilization that causes high throughput and low delay on the overall performance of the network improve. In future, authors intend to increase the number of APs so that RTS/CTS mechanism can also be incorporated which does not differ with basic access method in case of a single AP; as considered in this study.

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