Modelling and Empirical Analysis of IEEE 802.11b Distributed Coordination Function (DCF) In a Multi-Rate Wireless LAN

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***Abstract*—This paper presents an 802.11b Distributed coordinated function (DCF) approach that specifically concentrates on the multi-rate WLAN. In this approach we assume a saturated condition where every node in the network have a packet to transmit at any time and also a clear channel condition in which there is no hidden terminal in the network. This saturation throughput and delay are used to analyze the DCF. This work shows that in a slowly changing channel a smaller Sm and larger Fm for the ARF protocols needs to be set and used for better network performance.**

***Index Terms*—IEEE 802.11b, DCF, multi-rate WLAN, CSMA/CA, ARF**

I. Introduction

IEEE 802.11 protocols have become the most popular access technology in the world today. They provide an effective means of achieving wireless data connectivity in homes, public places and offices. In IEEE 802.11 protocols, the fundamental medium access method is called distributed coordinated function (DCF). The proper understanding and analysis of IEEE 802.11 DCF will bring about the better understanding of the performance of WLANS [1] - [5].

In [6], Bianchi proposed a 2-dimensional markov chain model to study the performance of a 802.11 DCF system with infinite buffer; but the model was not able to describe the congestion onset of the system. Many researchers including [7] – [10] dealt with the performance impairment at the Mac layer and concentrate on delay analysis of IEEE 802.11 adhoc networks in a finite load condition under the hidden terminal problem.

Weikuo Chu and Yu-chee tseng in [11] proposed an analytical model and use it to study the saturated throughput and delay performance of an 802.11 WLAN [12], in which the mobile hosts have multi-rate support.

However none of the above approaches dealt with the modelling and empirical analysis of 802.11b DCF using saturation throughput and delay in DCF analysis. Therefore, in this paper, we propose the modelling and empirical analysis of 802.11b DCF approach which specifically concentrates on the multi-rate WLAN. Here we assume a saturated condition where every node in the network has a packet to transmit at any time and also a clear channel condition in which there is no hidden terminal in the network. This saturation throughput and delay are used to analyze the DCF.

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The remainder of the paper is organized as follows. In section 2 the summary of the experimental test beds including measurements are presented. Section 3, 4 and 5 presents the throughput and delay analysis carried out and results obtained from the experiments, Finally section 6 concludes the paper and outlines future research directions.

II. Experimental Environment

This experiment is carried out in an indoor environment. Three different cases were considered in the experiment. The network is divided into three regions namely; region 1, region 2, and region 3. The three regions have ranges d1, d2 and d3 from the access points. In each of the three regions a fixed number of host were randomly distributed. The mobile hosts are laptops which have wireless LAN features and are IEEE 802.11b compliant.

Three different buildings in the three regions of the network are used as test beds to carry out the measurements on the network. In the first region, Nnedioranma hostel was used to carry out the experiment. Omeokachie hostel was used in the second region while university computers, a computer training school was used in the third region. In all the three regions, a software which is a network sniffer called Iperf was used to take measurement on the network.

A. Access Point Environment

The access points are located inside a computer training institute called Global microcosm computers and the office is located on the ground floor of a two storey building at Awka.

B. Test bed Environment

Test bed one: Nnedioranma Hostel

The first experiment was carried out in Nnedioranma hostel, which is 100m from Global microcosm computers. The hostel is a three storey building and the ground floor was used for the measurements. The ground floor has twenty rooms and six shops. Each room has a toilet and a bathroom and measures 4m x 3.8m x 2.7m.

In this building we consider seven different scenarios; first was with six mobile stations, second was with eight mobile stations, third was with ten mobile stations and it continues in that order till we have eighteen mobile stations. Each of the scenarios was set up by scattering the mobile hosts at different location inside the building. Signal measurements were taken by first dividing the building into squares of 1.5m by 1.5m. It is assumed that each square represent a node in the network.

Test bed Two: Omeokachie Hostel

The second experiment was carried out in omeokachie hostel, which is about 210m from the access point. The hostel is a two storey building and the second floor was used for the measurements. It is a two flat apartment each having four bedrooms, a living room, a kitchen, a veranda at the front and bathroom. The measurement of the entire second floor is about 25m x 12m x 3m. Each of the rooms measures 4m x 3m x3m. Seven scenarios were used in taking measurements on the building. As usual, the building was partitioned into squares of 1.5m by 1.5m before taking the measurement. Signal measurements were taken in five rooms and the two living rooms in each of the flats. In each of the seven scenarios considered in test bed two, a given number of mobile hosts were used. In the first scenario, six mobile hosts were used as the second eight were used, in the third ten were used and so on up to eighteen mobile hosts.

Test bed Three: University Computers, Awka

The third experiment was carried out in a computer training school called university computers Awka. It is 310m away from the access point. It has class rooms, a cyber cafe, offices and some public conveniences. The school which is on the second floor of a two-storey building was partitioned into squares of 1.5m by 1.5m. Signal measurements were taken using seven different scenarios in the building. A given number of mobile stations were scattered in the building each trying to communicate with the access points. Six mobile stations were used in the first scenario; eight were used in the second scenario while ten, twelve, fourteen, sixteen and eighteen mobile stations were used respectively.

C. An Overview of the three regions of the network

Here, we scattered the entire mobile host in the three regions we are considering; we also considered seven scenarios. In the first scenario, six mobile hosts were evenly scattered in all the three regions of the network, and signal measurements were taken. In the second scenario, eight mobile hosts were used while in the third to seventh scenarios ten, twelve, fourteen, sixteen and eighteen mobile hosts were scattered in all the three regions of the network respectively.

D. Signal Measurements

The following assumptions were made during the measurement;

- Each host always has a packet ready for transmission so that the saturation throughput performance of the network can be evaluated.
- The wireless channel quality depends on the distance between a sender and its receiver. That is, in addition to the packet collisions, a transmission will fail only when the maximum transmission range at a given rate is exceeded.
- The moving speeds of the mobile hosts are at most a few meters per second.
- There is no hidden terminal in the network.

Measurements were carried out on each of the test beds using the network sniffer called Iperf. The settings of the access points (Mikrotik and Linksys) were first configured and the network sniffer was used to measure the throughput, delay, signal strength, the MAC address, the access points types, the speed, the noise level, vendor etc. The table 1 is the summary of the input parameters used during the measurements.

TABLE 1: THE INPUT PARAMETERS USED DURING MEASUREMENTS

Parameters	Value
RTS Threshold	256 bytes
Time slot duration	20 µs
Channel data rate	11,5.5,2.0 Mb/s
Fragmentation threshold	256 bytes
SIFS	10 µs
DIFS	50 µs
Minimum contention window	31 slots
ACK	112bits +PHY
MAC Header	272 bits
PHY header	96 bits
Transmit Power	15 dbm
Packet Payload	1 k byte
Physical characteristics	DSSS
Short retry Limit	4
Long retry Limit	7
Packet Error Rate	0

III. ANALYSIS

The input parameters in table 1 were used to configure both access points AP1 (Mikrotik) and AP2 (Linksys).

In each region of the network, the successful (S_m) and failed (F_m) values of the ARF were set as follows;

S_m= 12, F_m=4

S_m=10, F_m=2

S_m=1, F_m=4

And the throughput, delay and signal strength measurements for each of the settings were taken.

A. Rate adaptation using auto rate fallback (ARF) algorithm

In this project we use the auto rate fallback (ARF) to adapt rate for different channel qualities. The relationship between the rates R that the sender uses to communicate with its receiver at a distance, d to the receiver are

$R= R_1, R_2, R_3, R\infty$ if $0 \le d \le d_i$

$R_{i-1}, R_i , R_2, R\infty$ i di-1 < $d \le d_i$

And $2 \le 1 \le\infty$ (1)

The relation (1) indicates that a sender will use all supported rates to send packets when d is in the range between 0 and d_i ; while the second relation indicates that the sender may try to use the R_{i-1} for transmissions when

$d_{i-1} < d \le d_i$ but such transmission suffers failure because this is out of transmission range.

B. Network Throughput

The normalized network throughput Thi , expressed$x =$ in mbps are defined as the fraction of the time that channel is used to successfully transmit user bit when the host are moving in any of the three regions of the access point is given as

$$\text{Thi} = \frac{\text{E(user bits transmitted in a time slot)}}{\text{E(length of a time slot)}} \quad (2)$$

E (users bits transmitted in a time slots) = $P_{tr} \times P^{isucc} \times L_{APP}$

(3)

Where P_{tr} = The probability that at least one transmission occurs on the channel in a randomly chosen time slot.

P_i = probability of successful transmission using rates R_1,R_2 and R_3 in the region i of the AP, given that at least one transmission is taken place on the channel.

L_{APP} = Packet size of the application layer

E(Length of a time slot) =(1 –P_{tr}) × σ + P_{tr} T^{isucc} + P_{tr} ×T^{ie} (4)

where T^{ie} = average time needed for a successful transmission in region i. Combining (3) and (4), a general equation for the normalized network throughput is given as

$$\text{Thi} = \frac{P_{tr} \times P_i \times L_{APP}}{(1 - P_{tr}) \times \sigma + P_{tr} \times T_i^{succ} + P_{tr} \times T_i^{e}} \quad (5)$$

IV. Throughput Measurement and Analysis

We divided the analysis into four stages. In the first, second and third stages, the throughput analysis were evaluated using region 1, region 2 and region3 of the AP. The fourth stage is a situation in which the hosts are moving in all the 3 regions of the AP.

Stage 1: All mobile hosts are moving only in region 1 of the AP. Table 2 shows the values of the throughput measured for each given number of mobile hosts and various ARF settings.

Let

Th_{11} =measured throughput in region 1 when the ARF setting is s_m =12, F_m = 4

Th_{21} = measured throughput in region 1 when the ARF setting is S_m = 10, F_m = 2

Th_{31} = measured throughput in region 1 when the ARF setting is S_m = 1, F_m = 4 therefore,

$Th_1$1 Ap_1 = measured throughput in region 1 for AP_1 when the AP's ARF setting are S_m = 12, F_m = 4

Th_{11} AP_2 = measured throughput in region 1 for AP_2 when the AP's ARF setting are S_m = 12, F_m = 4

Th_{21} AP_1 = measured throughput in region 1 for AP_1 when the AP's ARF setting are S_m = 10 , F_m = 2

Th_{21} AP_2 = measured throughput in region 1 for AP_2 when the AP's ARF setting are S_m =10, F_m =2

TH_{31} Ap_1 = measured throughput in region 1 for AP_1 when the AP's ARF setting are S_m = 1, F_m= 4

Th_{31} Ap_2 = measured throughput in region 1 for AP_2 when the AP's ARF setting are S_m = 1, F_m = 4

TABLE 2: Measured throughput values in region 1 of the AP's

No of Mobiles	$Th_{11}AP_1$ (MbPs)	$Th_{11}AP_2$ MbPs)	$Th_{21}AP_1$ (MbPs)	$Th_{21}AP_2$ (MbPs)	$Th_{31}AP_1$ (MbPs)	$Th_{31}AP_2$ (MbPs)
6	3.20	3.00	3.40	3.10	4.10	3.40
8	2.00	1.600	2.90	2.30	3.50	3.70
10	1.40	1.60	1.80	1.40	3.80	3.20
12	1.00	1.20	1.10	1.30	3.30	3.20
14	0.8	0.90	1.00	0.80	3.00	3.40
16	0.65	0.67	0.90	0.50	3.2	3.16
18	0.50	0.48	0.50	0.70	3.10	2.90

Fig.2 shows how the average throughput varies with different number of mobile hosts at various settings of the APs ARF.

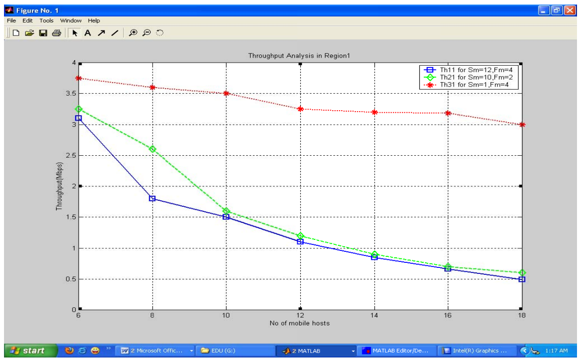

Fig. 2.A graph of the mean throughput against the number of mobile hosts in region 1

Stage 2: When all mobile hosts are moving in region 2 of the AP's, the values of the throughput measured for each given number of mobile hosts and for various ARF setting are shown in table 3

TABLE 3: Measured throughput values in region 2 of the AP's.

Number of Mobiles	$Th_{12}AP_1$ (MbPs)	$Th_{12}AP_2$ (MbPs)	$Th_{22}AP_1$ (MbPs)	$Th_{22}AP_2$ (MbPs)	$Th_{32}AP_1$ (MbPs)	$Th_{32}AP_2$ (MbPs)
6	3.00	2.60	3.20	2.80	3.70	3.30
8	1.60	1.40	2.70	2.30	3.22	3.28
10	1.10	1.30	2.20	1.80	3.20	2.80
12	1.20	1.80	1.30	1.10	3.10	2.50
14	0.90	0.70	0.90	0.70	2.60	3.00
16	0.60	0.60	0.60	0.80	2.40	2.80
18	0.58	0.42	0.52	0.68	2.40	2.60

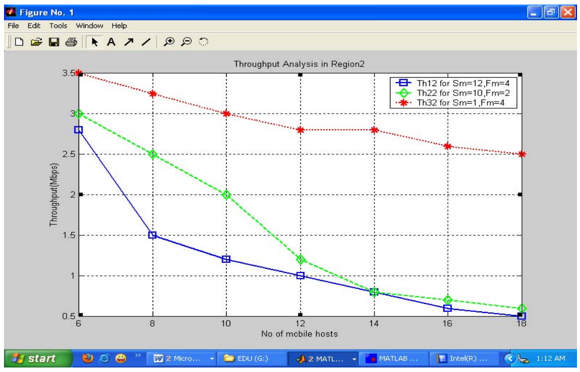

Fig. 3.A graph of the mean throughput against the number of mobile hosts in region 2

Stage 3: when all mobile hosts are moving in region 3 of the AP's the values of the throughput measured for each given number of mobile hosts and for various ARF setting are shown in table 4

TABLE 4: Measured throughput values in region 3 of the AP's.

Number of Mobiles	Th_{13} AP_1	Th_{13} AP_2	Th_{23} AP_1	Th_{23} AP_2	Th_{33} AP_1	Th_{33} AP_2
6	2.80	2.20	3.00	2.40	3.40	3.00
8	1.40	1.00	2.20	1.80	2.90	2.70
10	1.20	0.80	1.60	2.00	2.80	2.40
12	0.84	0.6	1.70	1.50	2.20	1.80
14	0.63	0.71	1.40	1.00	2.00	1.60
16	0.70	0.50	0.68	0.62	1.50	1.30
18	0.60	0.50	0.55	0.45	1.45	1.33

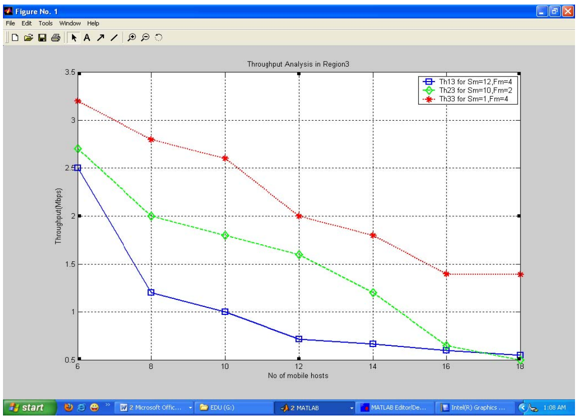

Fig. 4.A graph of the mean throughput against the number of mobile hosts in region 3.

Stage 4 : The general scenario

This is now the general scenario represents where the hosts are scattered in all the regions of the network. In this case, the throughput of the network can be evaluated by using the relationship

$$Th = \frac{d_1}{d_3} \times Th_1 + \frac{d_2 - d_1}{d3} \times Th_2 + \frac{d_3 - d_2}{d_3} \times Th_3$$

where

Th_1 =saturation throughput in region 1

Th_2 = saturation throughput in region 2

Th_3 = saturation throughput in region 3

Table 5 shows the values of the measured throughput for each given number of mobile hosts and for various ARF settings.

TABLE 5: MEASURED THROUGHPUT VALUES IN THE GENERAL CASE SCENARIO

Number of Mobiles	$Th_{1A}AP_1$ (MbPs)	$Th_{1A}AP_2$ MbPs)	$Th_{2A}AP_1$ (MbPs)	$Th_{2A}AP_2$ (MbPs)	$Th_{3A}AP_1$ (MbPs)	$Th_{3A}AP_2$ (MbPs)
6	3.69	2.71	2.30	2.70	4.10	3.30
8	1.70	1.30	0.90	0.70	3.10	2.90
10	0.70	0.66	0.84	0.72	2.90	2.70
12	0.68	0.62	0.80	0.68	2.56	2.88
14	0.66	0.60	0.67	0.75	2.69	2.61
16	0.61	0.55	0.74	0.64	2.80	2.20
18	0.58	0.50	0.69	0.69	2.50	2.10

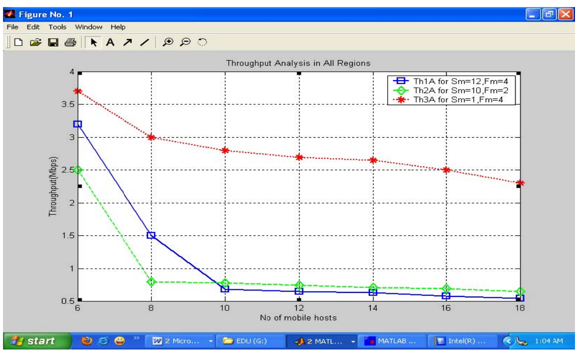

Fig. 5.A graph of the mean throughput against the number of mobile host in general scenario

V. DELAY ANALYSIS

The delay analysis is also divided into four stages

Stage 1: When all mobile hosts are moving in region 1 of the AP's, table 6 shows the values of the delay measured for each given number of mobile hosts.

Let

D_{11} = Measured delay in region 1 when the ARF setting is $S_m = 12$, $F_m = 4$

D_{12} = Measured delay in region 1 when the ARF setting is $S_m = 10$, $F_m = 2$

D_{31} = Measured delay in region 1 when the ARF setting is $S_m = 1$, $F_m = 4$

Therefore the measured delay for individual AP's can be given as

$D_{11}Ap_1$ = Measured delays in region 1 for AP_1 when AP's ARF setting is $S_m = 12$, $F_m = 4$

$D_{11}AP_2$ = Measured delays in region 1 for AP_2 when AP's ARF setting is $S_m = 12$, $F_m = 4$

$D_{21}AP_1$ = Measured delays in region 1 for AP_1 when AP's ARF setting is $S_m = 10$ $F_m = 2$

$D_{21}AP_2$ = Measured delays in region 1 for AP_1 when AP's ARF setting is $S_m = 10$, $F_m = 2$

$D_{31}AP_1$ = Measured delays in region 1 for AP_1 when AP's ARF setting is $S_m = 1$, $F_m = 4$

$D_{31}AP_2$ = Measured delays in region 1 for AP_2 when AP's ARF setting is $S_m = 1$, $F_m = 4$

TABLE 6: MEASURED DELAY IN REGION 1 OF THE AP_S

Number of Mobiles	$D_{11}AP_1$ (Seconds)	$D_{11}AP_2$ (Seconds)	$D_{21}AP_1$ (Seconds)	$D_{21}AP_2$ (Seconds)	$D_{31}AP_1$ (Seconds)	D_{31} AP_2 (Seconds)
6	0.90	0.70	0.70	0.50	0.32	0.28
8	1.20	0.80	1.00	0.80	0.50	0.50
10	1.30	1.10	0.90	1.30	1.10	0.70
12	1.41	1.25	1.40	1.20	1.10	0.90
14	1.30	1.42	1.40	1.30	6.80	1.40
16	1.50	1.30	1.30	1.46	1.30	1.10
18	1.52	1.40	1.51	1.33	1.23	1.27

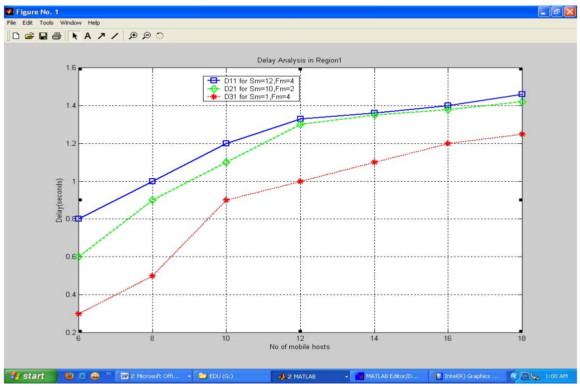

Fig. 6.A graph of the average delay against the number of mobile hosts in region 1

Stage 2: All mobile host in region 2 of the AP's

TABLE 7: MEASURED DELAY IN REGION 2 OF THE APS

Number of Mobiles	$D_{12}AP_1$ (seconds)	$Th_{12}AP_2$ (seconds)	$Th_{22}AP_1$ (seconds)	$Th_{22}AP_2$ (seconds)	Th_{32} AP_1 (seconds)	Th_{32} AP_2 (seconds)
6	1.40	1.00	0.70	0.90	0.30	0.50
8	1.80	0.80	0.80	1.20	0.55	0.65
10	1.35	1.65	1.10	1.70	0.70	1.30
12	1.60	1.80	1.50	1.70	0.90	1.50
14	1.46	2.00	1.54	1.76	1.20	1.28
16	1.71	1.86	1.62	1.84	1.18	1.36
18	1.67	1.93	1.64	1.92	1.28	1.32

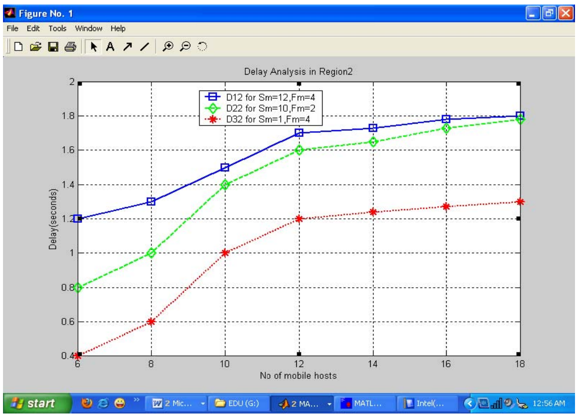

Fig. 7.A graph of average delay against the number of mobile hosts in region 2

Stage 3 : All mobile hosts in region 3 of the AP's

TABLE 8: MEASURED DELAY IN REGION 3 OF APS

No of Mobiles	D_{13} AP_1 (seconds)	Th_{13} AP_2 (seconds)	Th_{23} AP_1 (seconds)	Th_{23} AP_2 (seconds)	Th_{33} AP_1 (seconds)	Th_{33} AP_2 (seconds)
6	1.22	1.30	0.70	1.10	0.40	0.56
8	1.20	1.60	1.00	1.60	0.52	0.68
10	1.40	1.60	1.20	1.80	0.70	1.10
12	1.50	1.64	1.35	1.75	1.40	1.00
14	1.48	1.72	1.50	1.74	1.24	1.30
16	1.70	1.80	1.80	1.60	1.10	1.50
18	1.70	1.90	1.62	1.94	1.20	1.48

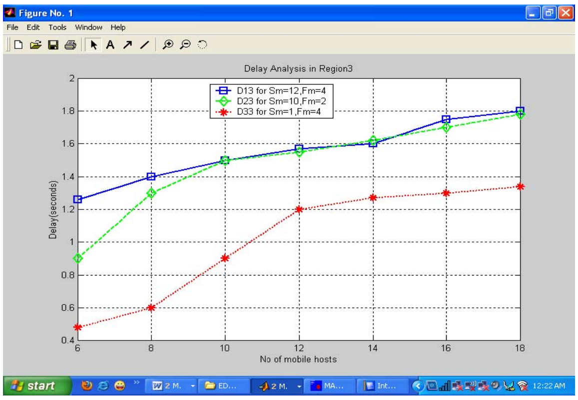

Fig. 8.A graph of average delay against the number of mobile hosts in regions 3.

Stage 4: The general scenario

In the general Scenario, the average delay for host moving in 3 regions of the AP can be evaluated as follows: $E(D) = \frac{d_1}{d_3} \times E[D_1] + \frac{d_2 \times d_1}{d_3} \times E[D_2] + \frac{d_2 \times d_3}{d_3} \times E[D_3]$

Where D_1 = average delay in region 1

D_2 = average delay in region 2

D_3 = average delay in region 3

Let

D_1A = measured delay in general scenario for $S_m = 12$, $F_m = 4$

D_2A = measured delay in general scenario for $S_m = 10$, $F_m = 2$

D_3A = measured delay in general scenario for $S_m = 1$, $F_m = 4$

D_1A Ap_1 = measured delay in general scenario for AP_1 with $S_m = 12$, $F_m = 4$

D_2A Ap_1 = measured delay in general scenario for AP_2 with $S_m = 10$, $F_m = 2$

The table below shows the measured delays in the general scenario.

TABLE 9: MEASURED DELAY IN THE GENERAL SCENARIO

Number of Mobiles hosts	$D_{1A}AP_1$ (seconds)	$Th_{1A}AP_2$ (seconds)	$Th_{2A}AP_1$ (seconds)	$Th_{2A}AP_2$ (seconds)	$Th_{3A}AP_1$ (seconds)	$Th_{3A}AP_2$ (seconds)
6	0.36	0.24	0.57	0.43	0.17	0.13
8	0.74	0.66	0.96	0.84	0.25	0.19
10	1.40	1.00	1.22	0.98	0.26	0.28
12	1.46	1.54	1.32	1.28	0.31	0.29
14	1.74	1.42	1.35	1.45	0.35	0.33
16	1.67	1.53	1.62	1.48	0.42	0.32
18	1.82	1.58	1.64	1.56	0.42	0.38

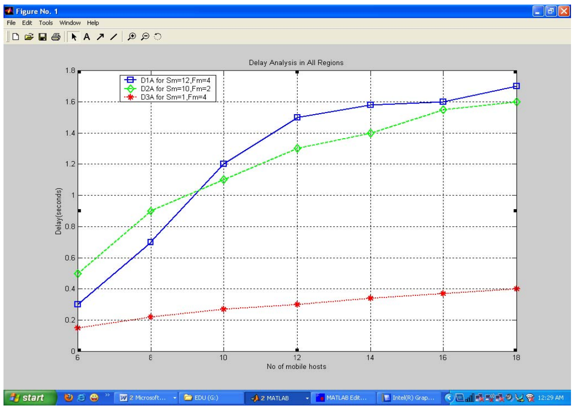

Fig. 9.A graph of average delay against number of mobile hosts in the general scenario.

From the graphs in the figures 2, 3, 4 and 5 we observed that generally in all the regions that the throughput decreases as the number of mobiles increases. Also we observe that the throughput performance of the net work is better when a smaller S_m and a larger F_m values are used. On the other hand, a very high value of Fm will have negative effect on throughput performance when a host is crossing the border from a region nearer the AP to the region from the AP. From the delay analysis shown in figures 6, 7, 8, and 9 we observed that the average delay increases as the number of mobiles increases. Also we observed that a lower delay can be obtainable whenever a smaller S_m and a larger Fm are used.

VI. CONCLUSION AND FUTURE WORKS

In this work, we have presented a model for IEEE 802.11b multi-rate WLAN. The ARF protocol is adopted by wireless interfaces for choosing transmission rates. We carried out an empirical analysis of IEEE 802.11b distributed coordinated function (DCF) in a multi-rate WLAN using the ARF protocol to adapt rates for different channel qualities. From the analysis, we conclude that in a slowly changing channel, a smaller S_m and a larger Fm for the ARF protocols needs to be set and used for better network performance.

This work was carried out in an ideal wireless channel, considered as a slowly changing medium by setting the packet error rate to be zero. We therefore suggest that further worksshould be done by making use of mobile hosts moving at a very high speed, and also making the packet error rate to more closely reflect the real situation.

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