Performance Evaluation of WLAN Internet Sharing Using DCF & PCF Modes

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Abstract *Recently, Wireless Local Area Networks (WLANS) has become one of the most popular standards for wireless Internet access technology. IEEE 802.11 WLAN standard supports two kinds of access methods: DCF (Distributed Coordination Function) and PCF (Point Coordination Function).In this paper, DCF & PCF modes were used to manage internet sharing tasks. The characteristics obtained from bandwidth-delay measurements of a real Wireless Internet Service Providing (WISP) system were used to build an analogue OPNET simulation model. Using this model, internet access performance as a function of sharing strategies were evaluated when subjected to either(or both) PCF or DCF modes. The obtained results indicate that both modes have its own work space and care should be paid in adopting both of them in an efficient and accurately planned manner.*

Keywords: *Internet Sharing, WLAN, DCF, PCF, Page Response Time Received; accepted*

1. Introduction

Wireless technologies are playing an increasingly prominent role in the global Internet infrastructure. One of the popular technologies is the IEEE 802.11 standard. This popular "WiFi" (Wireless Fidelity) technology provides low-cost wireless Internet capability for end users, with up to 54 Mbps data transmission rate at the physical layer. Wireless medium is a shared medium, so as more and more devices demand the bandwidth, concentrating on performance becomes critical. As the wireless LANs are giving a competition to the Ethernet, apart from speed it will also have to assure the Quality of Service, especially when dealing with voice, video and other real time services [1].

IEEE 802.11 standard has two sublayers MAC protocols: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF supports best effort delivery of packets while the PCF is built on the top of DCF and provides services for time-bounded traffic [2]. The 802.11 MAC layer aims to provide access control functions to the wireless medium such as access coordination, addressing or frame check sequence generation. Two different classes of wireless configuration have been defined for 802.11. An *Infrastructure Network*, where many stations can communicate with the wired backbone through an access point (AP), and the *Ad Hoc Network*, where any device can communicate directly with other devices, without any connectivity to the wired backbone. A group of stations coordinated by 802.11 MAC functions is called a basic service set (BSS) in *infrastructure mode* and independent BSS (IBSS) in *ad-hoc mode*, respectively. The area covered by the BSS is known as the basic service area (BSA), which is similar to a cell in a cellular mobile network [3] Layer two performance of DCF & PCF modes have been studied by many researchers [4]-[6]. The effect of different polling strategies on PCF performance is presented in [7] while the performance of video transmission with PCF has been investigated in [8], [9]. Suzuki et al. [10] proposed priority-based multimedia transmission with PCF, which gives the priority control to AP or both AP and the stations, and then AP decides whether to poll or not based on the priority of the stations.

Most of the above studies concentrate on the PCF impact on layer two performance or the benefits obtained from adopting PCF mode in real time applications. On the other hand, the current paper focuses on the effect of adopting different MAC sublayer modes (DCF & PCF) on the internet sharing performance.

2. IEEE 802.11 MAC layers

As mentioned earlier, the IEEE 802.11 MAC sub-layer defines two medium access coordination functions, the basic Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF) [11].

●**Distributed Coordination Function (DCF):** DCF is an asynchronous transmission mode based on Carrier Sense Multiple Access with Collision Avoidance scheme (CSMA/CA). As shown in Figure (1), if a packet arrives at an empty queue and if the medium has been found idle for an interval of time longer than a distributed interframe space called DIFS, the source station can transmit the packet immediately. Meanwhile, other stations defer their transmissions and start the backoff process. Once the backoff timer expires, the station is authorized to access the medium.

Collisions occur when at least two stations start transmission simultaneously. On this purpose, a positive acknowledgement (ACK) is used to notify the sender that the transmitted frame has been successfully received, see Figure (1). If the ACK is not received, the sender assumes that there is a collision, and it schedules a retransmission by entering the backoff process again. Hidden terminals can also induce collisions. These terminals are stations that the receiver can hear but that cannot be detected by other senders. Consequently, frames sent from different senders will collide at the same receiver. To solve this problem, the RTS/CTS scheme can optionally be used: the source sends a short RTS frame before each data frame transmission, see Figure (1), and the receiver replies with a CTS frame if it is ready to receive. Once the source receives the CTS frame, it transmits a frame. All other stations hearing a RTS, CTS, or a data frame in the BSS update will not start transmissions before the updated Network Allocation Vector (NAV) timers reach zero. The RTS/CTS scheme improves significantly the performance of the basic DCF scheme when data frame sizes are large. DCF is mandatory in the standard and can be used both in ad-hoc and infrastructure modes [3], [5], [8].

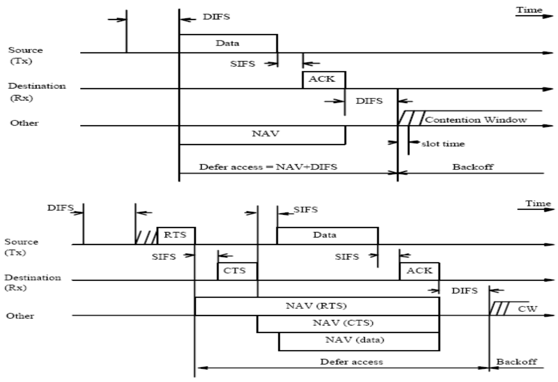


Figure (1): DCF access mechanism: CSMA/CA (up) and RTS/CTS scheme (down)

●**Point Coordination Function (PCF):** Priority-based access can also be used to access the medium. For example, PCF is a synchronous service that implements a polling-based contention-free access scheme. It can be used with the infrastructure mode only. Unlike DCF, its implementation is not mandatory. The reason is that the hardware implementation of PCF was thought to be too complex at the time the standard was finalized. Furthermore, PCF itself relies on the synchronous service provided by DCF and the beacon interval must allow at least one DCF data frame to be transmitted during the CP. PCF uses a centralized polling scheme, which uses the AP as a point coordinator (PC). When a BSS is set up with PCF-enabled, the channel access time is divided into periodic intervals named beacon intervals, see Figure (2). The beacon interval is composed of a contention-free period (CFP) and a contention period (CP). During the CFP, the PC maintains a list of registered stations and polls each of them according to the list. When a station is polled, it starts to transmit data frames, where the size of each data frame is bounded by the maximum MAC service data unit size. The time used by the PC to generate beacon frames is called target beacon transmission time (TBTT). The next TBTT is announced within the beacon frame by the PC to inform all other stations in the BSS. To give PCF higher priority of access than DCF in a beacon interval, the PC waits for a shorter interframe space than DIFS (called PIFS standing for PCF interframe space), before starting the PCF. But PCF is not allowed to interrupt any ongoing frame transmissions in DCF. Then, all other stations set their NAVs to the values of *CFP max duration*, or the remaining duration of CFP in case of delayed beacon. A typical medium access sequence during PCF is shown in Figure (2) [12].

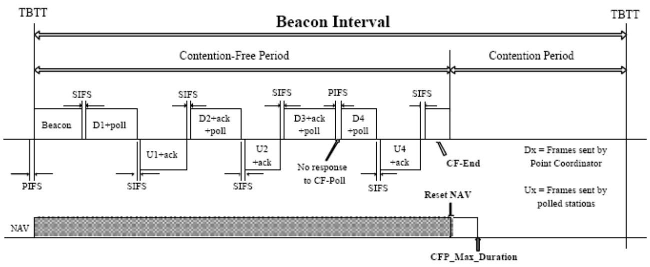


Figure (2): *PCF and DCF cycles*

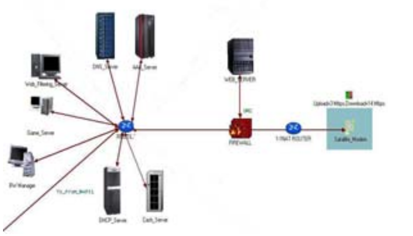
Once PCF obtains access to the wireless medium, SIFS timing is used for frames exchanges during CFP except if the polled station does not respond the PC within a PIFS period. When a PC polls a station, it can piggyback the data frames to the station together with the CF-Poll, then the station sends back a data frame piggybacked with an ACK after a SIFS interval. When the PC polls the next station, it piggybacks not only the data frame to the destination, but also the ACK corresponding to the previous successful transmission. Silent stations are removed from the polling list after several periods and may be polled again at the beginning of the next CFP. Note that at anytime, the PC can decide to terminate the CFP by transmitting a CF-End frame. Usually, PCF uses a round-robin scheduler to poll each station sequentially in the order of the polling list, but priority-based polling mechanisms can also be used if different Quality of Service (QoS) levels are requested by different stations [13].

3. Performance Investigation of a Wireless Internet Service Providing (WISP) System

3.1 System Description

In order to investigate internet sharing performance (using DCF based wireless network), practical measurements on a real Wireless Internet Service Providing (WISP) system were achieved. The WISP system under study can be considered as the major internet service provider in the city of Mosul/Iraq. The system gives various services to its clients, such as, Internet browsing, E-mail services, web hosting, HTML pages design, distributed gaming and numerous commercial activities.

From the technical point of view, Internet services providing is considered to be the major activity of the system. It uses multiple wireless/wired network techniques to cover the different areas of the city. Figure (3) gives a clear picture of the network.



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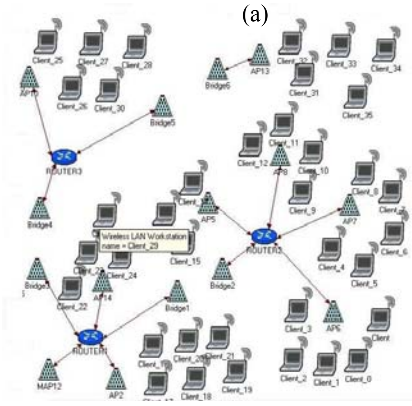

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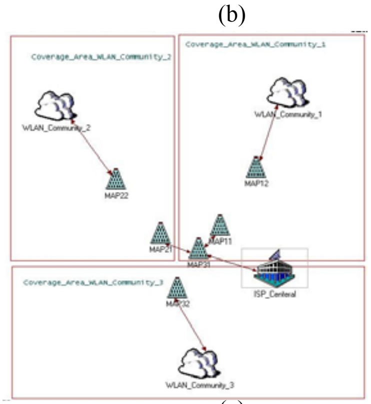


(c)

Figure (3). Structure of WISP System: (a) ISP (Management) Centre (b) Distribution Network (c) The Whole System

The network spans about (25×25 Km) of the city area. The major elements of the system are the distribution network and the ISP centre.

● **the distribution network:** It is the various links between the clients and the ISP centre. The traffic to/from the centre is forwarded through three pairs of point to point bridges, we called Major Access points (MAP); each one of them is responsible of covering certain areas of the city. The point to point wireless links between them are subjected to IEEE802.11g WLAN standard, running at a speed of (22 Mbps). The rest of the network consists of local access points (working at 11 Mbps data rate of IEEE 802.11b WLAN standard and subjected to the default *DCF mode* operation) installed in different sections of the city to serve certain number of users. The coverage area of each access point is maintained through the use of proper antennas and if necessary, suitable signal boosters. Figure (4) shows the distribution of the installed access points with their relative users.

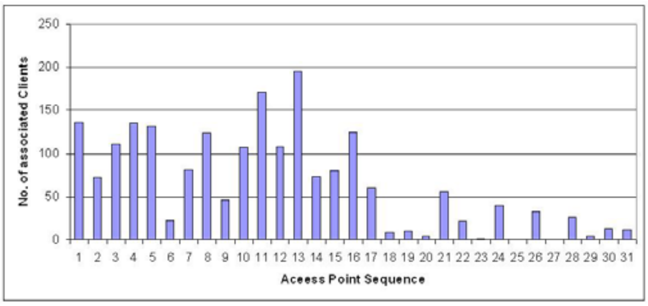


Figure (4): The Distribution of the Access Points with Their Relative Users

● **The ISP Centre:** It consists of various network devices and servers to manage and provide internet services, see Figure (3). Their functions could be summarized as follows:

♦Satellite Modem: It is the link between the ISP and the rest of the internet. It has a data rates of (15 Mbps) for download and (3 Mbps) for upload operations.

♦1-1 NAT Router: The system has an (1500) public IP addresses pool available to the clients on the *one to one* Network Address Translation basis (i.e., each public IP is given to a private IP address during user log in time).

♦A Firewall supported with Intrusion Detection System (IDS) capabilities provides certain level of security to the system. The company's web server is connected to the *demilitarized zone* (DMZ) portion of the firewall device. The firewall allows limited access to the DMZ, but because the DMZ only includes the public servers, an attack there only affects the servers and does not affect the other inside networks [14].

♦AAA Server: AAA is the acronym for Authentication, Authorization, and Accounting. Authentication controls access by requiring valid user credentials, which are typically a username and password. Authorization controls access *per user* after users authenticate. Accounting tracks traffic that passes through the security appliance, gives the ability to have a record of user activity [14].

♦ Web filtering server together with the cache server frees more bandwidth for the benefit of the most important needs.

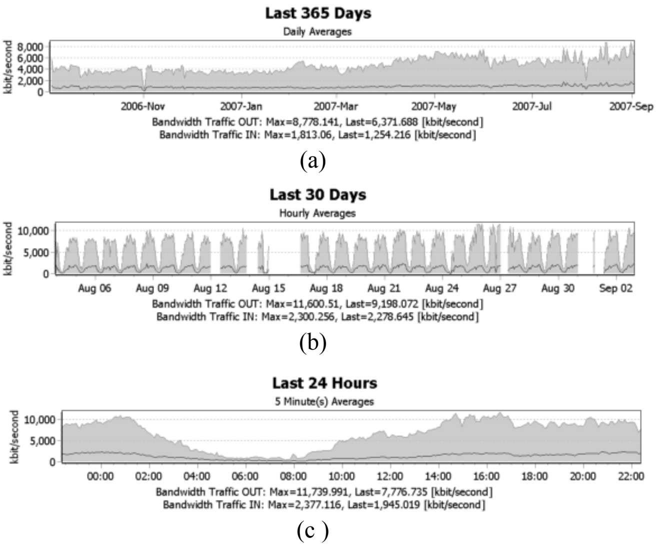
♦Bandwidth Management Server: It is responsible for giving a certain level of service to the different clients according to their individual subscriptions. Each client is given a certain amount of bandwidth using several bandwidth management techniques. Also, many subscriptions have a pre defined amount of *transferred data per month*.

♦The WEB Server contains the web site of the company and hosted web sites for some individuals.

♦At last, Domain Name Server(DNS) and Dynamic Host Configuration Protocol(DHCP) servers provide their usual tasks , such as translating IP addresses to a domain names (DNS function) and supplying the connected users with their corresponding IP addresses(DHCP function)[14].

3.2 Practical Test Results

In order to evaluate the load situation of the system, a comprehensive load tests were made. The tests were implemented at different points on the network to give the maximum level of knowledge about the system. These points are: the satellite modem, content (http traffic) filter, Major Access Points (MAPs), a highly loaded local access point (AP4) and a lightly loaded access point (AP28). The data were collected for a year, month and day periods, see Figure(5).



Figure(5). Load Test Results

The following remarks could be extracted from the tests:

1. The yearly average value of the downloaded traffic occupies (58.5%) of the available (15 Mbps) download bandwidth, while it consumes (60%) of the available (3 Mbps) upload bandwidth.

2. Http traffic occupies (85%) of the whole download bandwidth. Other applications are: file transfer applications (FTP), E-mail applications (SMTP), Domain Name Server Protocols (DNS) and Chatting protocols which share the remaining bandwidth.

3. The daily traffic load applied to the system changes periodically between a low load period (16% of the available download bandwidth, from 4 to 10 am) and high load periods (78% of the available bandwidth) for the rest of the day.

4. The average throughput of the local access points indicates an average user throughput of (4 kbps).

In order to investigate the different contributors of the total network response time, system latency is measured. This is done using a *PING* command originating from different sources in the network to a certain server in the ISP centre during 3 days period, see Figure(6).

The purpose of these experiments is to determine the real reason behind performance change in the different situations. We chose two local access points, highly loaded access point (AP4) and a lightly loaded access point (AP28). These access points serve different number of clients and have comparable path lengths to the central ISP. Four latency measures are done: from local access points to ISP centre (PING1 & PING2), from a HOST to ISP centre (PING3) and from ISP centre to the internet (PING4). The latency values result from the different measurements are seen in Figure (7).

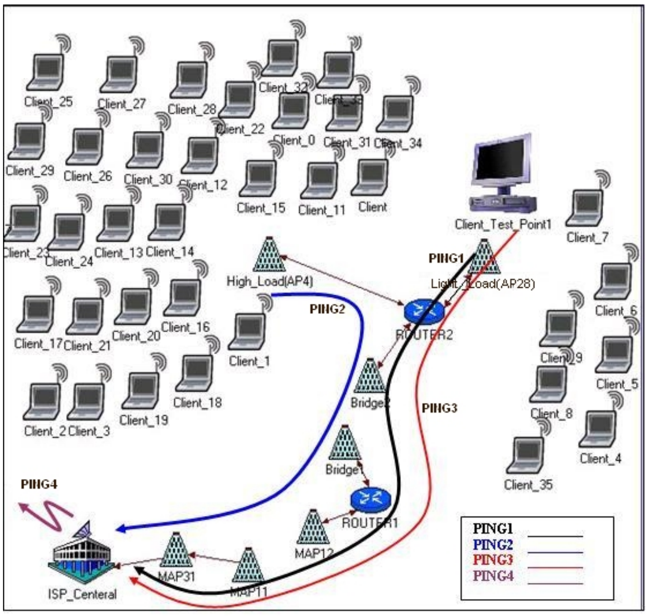
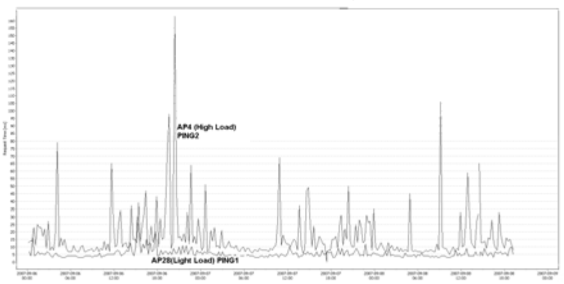


Figure (6). Network Setup of Latency Measurements



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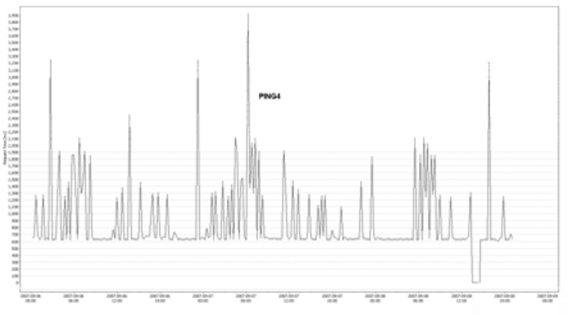

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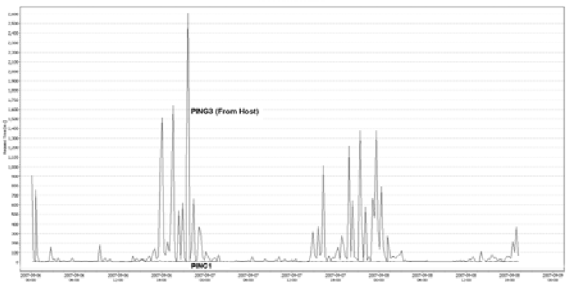


(c)

Figure (7). Latency Measurements (a) PING1 & PING2 (b) PING1&PING3 (c) PING4

In these experiments, latency was measured as the summation of three parts:

1. from a client to the ISP centre: One of the hosts is configured to send continues *PING* commands to the ISP centre. Figure (7b) shows that this latency has an average value of (137 ms) and subjects to the daily load distribution mentioned earlier. A comparison of this latency values to the results of Ping1 (from an access point to ISP centre) shows a higher contribution of this part of the network in the total latency calculations. This is caused mainly by the contention nature of the CSMA/CA protocol (working under DCF mode) and its performance dependence on the number of served clients.
2. from local access point to the ISP centre: The average values of this latency are (5 ms) for the lightly loaded access point (AP28) and (17 ms) for the highly loaded access point (AP4), see Figure (7a). It is obvious that this latency value is considered as a minor contributor and depends mainly on the number of contestant clients related to each access point.
3. from ISP centre to the Internet: We chose *Yahoo* server as the destination in this experiment because of its popularity (it was the *home page* for 70% of the users). The average latency value in this case is (885 ms) and caused mainly by the effect of the propagation time to the geostationary satellite. The noted fluctuations in the latency results from various load conditions during test time see Figure (7c).

Total *two way network latency* could be calculated as the summation of both (ping3 and ping4) values and have the average value of (1022 ms).

It is obvious that latency value of the system is remarkably affected by the number of the contended stations on the same access point and subjected to the behaviour of the DCF mode.

4. Building an OPNET Simulation Model

In order to investigate the effect of adopting the different MAC sub layer techniques on the Internet sharing performance, an OPNET simulation model analogue to the real system mentioned earlier was built, see Figure(8).

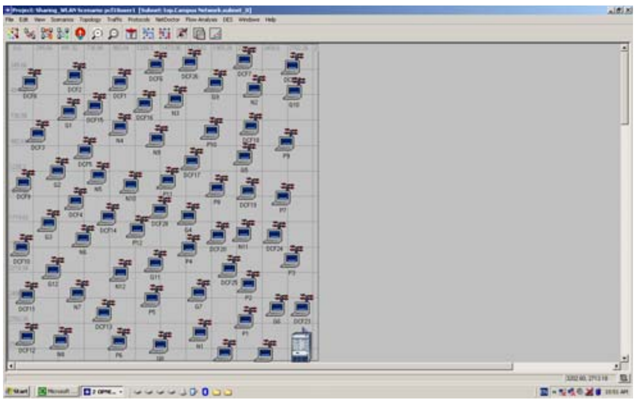


Figure (8). An OPNET Simulation Model

The following assumptions were considered during building the simulation model:

1. In order to focus on the effect of MAC sub layers behaviour on the internet sharing performance, our simulation model was built to represent a single cell (an Access Point (AP) served certain number of users). The cell has a WLAN connection to the ISP centre in an equivalent manner to the practical system. Figure (9) shows the settings of WLAN parameters made to each node in the cell.
2. According to the practical measurements, HTTP was the dominant Internet application. For the sake of model simplicity, it was considered as the only application. The users were assumed to have an identical Web behaviour and have an equivalent *Yahoo* web page characteristics as listed in Table(1). Also, the value of page Inter-arrival time (and scheme) by each

client takes into account the load behaviour as shown earlier in the load tests, See Figure (10).

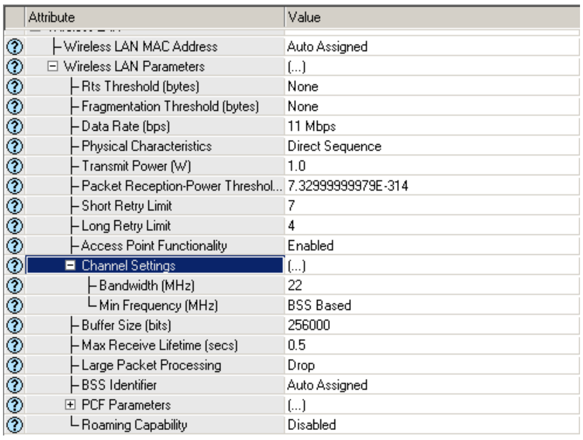


Figure (9): WLAN Nodes Settings

Table (1). Yahoo Web Page Properties

No. of Objects	23
No. of Image Objects	17
No. of Java Script Objects	4
No. of Style Sheet Documents	1
No. of Flash Objects	1
HTML Code Size(Kbytes)	133
Total Page Size(Kbytes)	566

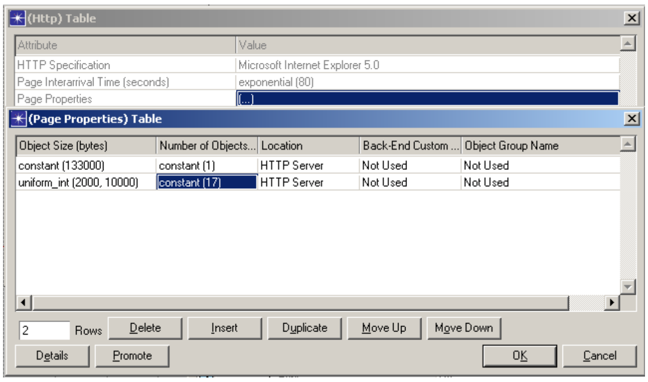


Figure (10). Web Page Characteristics of the Simulation Model

3. The metric used to evaluate the system performance was the average web response time. It can be defined as the average time needed to completely download a web page from an HTTP server to the claimed client [11]. In order to concentrate on the WLAN MAC Sub layers protocols effect (excluding internet effect), the web pages were assumed to be downloaded from a Cash server located at the ISP centre.

4. In OPNET environment, access points working in PCF mode use a round-robin scheduler to poll each station sequentially as ordered in the polling list.

5. In the simulation model, spatial nodes distribution and their cell dimensions were set identical to that of the practical system.

5. Results and Discussion

In this section, several scenarios were built to test network performance under various circumstances. The goal is to determine the important parameters affecting internet sharing characteristics.

- **Scenario 1: DCF and PCF effects on network services**

In this scenario, page response times of two identical networks were compared. The first network consists of nodes sharing internet and working under DCF mode, while the other adopts PCF mode with Collision Free Period (CFP) equal to (0.02 sec.) for the access point (total time given for the stations working in PCF mode) and (0.01 sec.) for the nodes(i.e., the client is polled each 0.01 sec.). The number of stations increased gradually and the web response times were recorded in each case, see Figure (11).

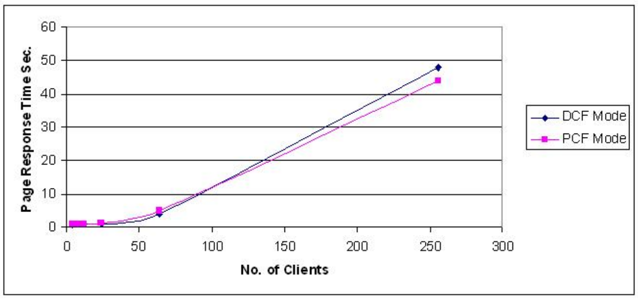
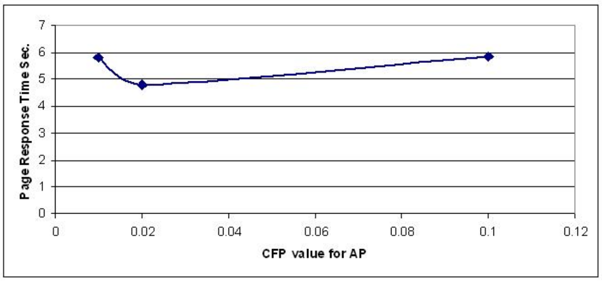


Figure (11). Page Response Time for PCF & DCF Modes

It is noted that working in PCF mode results in larger delay in small-size networks (less than 100 nodes) due to polling overheads (which adds unnecessary delay to the queued requests from the polled stations). On the other hand, working in DCF mode performs well till networks size is relatively small(less than 100 node) and suffers from Web response time degradation at high load and in large-size networks.

●Scenario 2: Investigating PCF mode Parameters

In this scenario, the number of clients (working in PCF mode) was fixed on (64 node) and the effect of varying CFP values for both access point and the nodes is investigated. CFP for the access point gives total time given for the stations working in PCF mode, while it indicates the duration between two successive polling operations to the client. Figure (12) shows that the chosen values for these parameters must take into account several aspects such as the load expected to/from the nodes, number of nodes and the level of service provided to the clients. In this particular situation, the optimum values for access point was (0.02 sec.) and (0.0005 sec.) for the clients.



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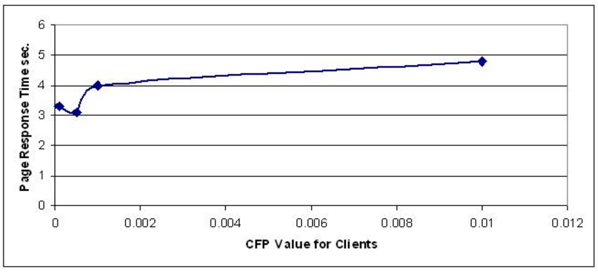

(b)

Figure (12). Effect of CFP Values on Page Response Time (a) Access Point (b) Clients

● **Scenario 3: Network working in both PCF & DCF modes**

In this case, the performance of a simulated network consists of (64 node) was examined. The nodes were segmented into two groups: 32 nodes working in DCF mode and 32 nodes working PCF mode (with Access point CFP = 0.018 sec., Nodes CFP = 0.009 sec. and Beacon interval = 0.02 sec.). The above values give PCF nodes more priority over DCF nodes (given more reserved time to handle their traffic), which affect positively on their average web response values (2 sec.) compared to the nodes working under DCF mode criteria which have an average web response time of (23 sec.). DCF nodes have less time to handle their traffic because their lower priority.

● **Scenario 4: Adding priority concepts in WLAN internet sharing**

In this scenario, the effect of assigning the nodes different CFP values (for priority purposes) is investigated. An (64 nodes) network was segmented into 28 DCF nodes plus 36 nodes working in PCF mode. The PCF nodes were sub-segmented into three (12 nodes) groups with different CFP values. The PCF mode parameters were as follows: CFP for access point is (0.018 sec.), Beacon interval value of (0.02 sec.), CFP1 (for polling list1) = 0.0005 sec., CFP2 (for polling list2) = 0.001 sec. and CFP3 (for polling list3) = 0.005 sec. Table (2) lists the average web response time for the above cases. It is obviously clear that assigning different values of CFP to the nodes allow for better management of the system and gives more differentiation between the nodes according to their PCF mode parameters.

Table (2). Priority Effect on Page Response Time

WLAN MAC Sub-layer Mode	Number of Nodes	Average Web Response Time(sec.)
DCF	28	52
PCF1 (CFP=0.0005 sec.)	12	1.7
PCF2 (CFP=0.001 sec.)	12	2.8
PCF3 (CFP=0.005 sec.)	12	7.3

6. Conclusions & Suggestions for Future Work

In this paper, Internet sharing characteristics using different WLAN modes is studied. WLAN working under DCF mode suffers from high latency value when the traffic offered to the network exceeds certain limits (depending on the network size and the load demands of its clients) because of the contention nature of this mode. On the other hand, PCF mode offers higher degree of determinism to the network clients but suffers from the negative effect of polling overhead in the case of low load conditions. The wise selection of PCF parameters must takes into consideration several aspects such as the load expected to/from the nodes, number of nodes and the level of service provided to the clients.

Our future work may include the following points:

●The author suggests the development of a switching criterion, in which, the access point would switch between PCF or DCF modes as network load change.

●Also, there is a real need to develop a PCF scheduling scheme (other than round robin) takes into consideration Internet sharing optimization.

● the third direction is to find an exact mathematical relation between network load parameters and the optimum value of CFP for the access point and the nodes.

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