Achieving Stable Throughput to Support QoS in IEEE 802.11 Wireless Networks

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***Abstract*-This paper investigates and describes a new provisioning technique for IEEE 802.11 based networks, focusing on the ad-hoc Distributed Coordination Function (DCF) to redefine stability of the network throughput to support QoS. This paper propose better techniques to achieve stable throughput in Wireless LAN networks by assigning new values to the Contention Window to high priority traffics which will guarantee better throughput to the selected network traffic. A simulation is done using Network Simulator 2 (NS-2) and findings are then presented. Results showed that stable throughput can be achieved to provide better traffic flows especially for real-time traffic and multimedia applications.**

I. INTRODUCTION

Wireless Local Area Network (WLAN) has emerged as an alternative to access the network and the Internet. The price drop of wireless Network Interface Card (WNIC) from $695 in 1999 to $24.99 in 2004 [1] was the main factor of boosting the popularity of WLAN as the main network of choice. The strong and growing demand for WLANs in both consumer markets such as residential networks [2] and industrial markets such as retail, education, health care and wireless hot-spots in hotels, airports, and restaurants [1] has been documented repeatedly in business, industry and education [3].

One of the main reasons of the popularity of wireless network is that users can access the network without being physically attached. This means they can reach the Internet wherever they are, whether they are in the office or at home whenever and wherever they want. With the wireless network technology becomes more matured, a lot of improvements had been made to enhance it. This includes reduced errors in health care facility (where the “anytime anywhere” aspect of wireless communications allows increased access to accurate information when needed most), time saving, improved profitability in terms of cost saving for cabling and labour and flexibility [1]. With the encouraging growth of wireless network usage which saw increased productivity as much as 22% from a research of end users and IT network administrators of more than 300 U.S.-based organizations [4], it is seen that pervasive high-speed wireless data services are both compelling and inevitable.

As the network world becomes more popular, the network load has become a critical issue. The wired LAN, which was originally designed to carry data traffic (such as file transfer, e-mail and Internet browsing) is now being used to carry real-time and multimedia traffic such as video and voice. With the rising popularity of WLAN today, applications traditionally used in wired LAN are now increasingly being used in WLAN

Highly congested network are demanding for better enhancement to support Quality of Service (QoS) that requires fast yet reliable transmission, where one of the attribute of an ideal QoS property is a stable throughput [3] which sustains the throughput at a certain consistent level. This includes applications such as internet banking, and multimedia across networks which require real-time traffic such as video streaming and voice over internet protocol (VoIP).

Over the past few years, researchers had come with various solutions to provide QoS. These include QoS provisioning on layer two such as packet based flow and the upper layer such as queuing algorithms and traffic shaping. However, most of the algorithms proposed are designed specifically for wired networks. Since the method on medium accessing for wired and wireless network are completely different, the proposed algorithm or technique may not be suitable to be implemented directly on the wireless medium.

The remainder of this paper is organized as follows. Firstly, this paper will discuss on the IEEE 802.11 channel coordination function before focusing on the Distributed Coordination Function (DCF) channel access method. Then, other proposed techniques from previous research are presented before outlining the author’s proposed techniques. Finally, a brief description of simulation scenarios and findings are given.

II. IEEE 802.11 CHANNEL COORDINATION FUNCTION

WLAN uses radio frequencies to communicate, share data and transfer files in half-duplex mode. Radio frequency can be used only by one device at a time; therefore there will be a method for the devices to take turns to use the radio frequency channel to avoid collision, which is called the coordination function.

There are two types of WLAN 802.11 coordination function which is defined by the IEEE 802.11, which are the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF). DCF is used for asynchronous contention based distributed accesses to the channel while the latter is used in the centralized, contention-free accesses. Since this paper focuses on DCF, the following subsection will discuss more on DCF [5] access method.

A. *IEEE 802.11 Distributed Coordination Function (DCF)*

DCF is used specifically for the contention-based channel access method. This means client nodes contend or compete with each other to use the network channel. In the contention basis, any client nodes can attempt to transmit data at any time it wanted to. However, the problem occurs when two computers start to transmit data at the same time, where a collision will definitely happen. DCF adopts the Ethernet, IEEE 802.3 Carrier Sense Multiple Access with Collision Detection (CSMA/CD) mechanism with several modifications, which is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. Whereas CSMA/CD is used to handle collisions after it occurs (by retransmitting the damaged packet), CSMA/CA avoids the collisions altogether which can be illustrated in Figure 1.

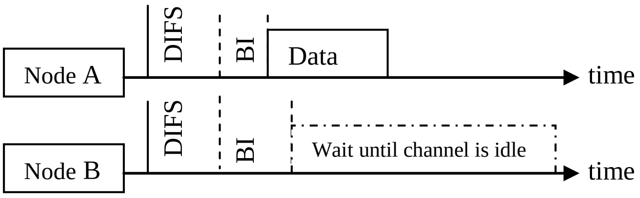

Figure 1. The operation of DCF mechanism

CSMA/CA does not wait for collisions to occur to handle collision avoidance. Figure 1 shows how the DCF mechanism operates to avoid collision before it actually occurs. Instead of having the two clients, Node A and Node B responsible for the collision to wait a random amount of time (as in CSMA/CD), CSMA/CA has all the clients to wait for a random amount of time, T_{wait}, which consists of DCF Interframe Space (DIFS), and backoff interval (BI) which is also known as the Contention Window (CW), before attempting to do transmission, as shown in **(1)**. BI is a uniform random value, sampled exponentially from [0, CW].

$$\boldsymbol{T_{wait} = DIFS + BI} \qquad (1)$$

Although the value of DIFS is the same for each station, the BI value is taken randomly to avoid collision. On the other hand, DIFS is derived from an equation as in **(2)** below:

$$\boldsymbol{DIFS = 2\ (Slot\ time) + SIFS} \qquad (2)$$

It is known that all of the stations will have the same value of DIFS because SlotTime and SIFS are both constant value of 9 µs and 10 µs respectively [6], while the BI value is the parameter which finally determines which node will use the channel first. Therefore, the value of the BI or CW is taken into account as the main focus of this research.

III. Related Works in Contention Window Tuning

WLAN had been a critical issue in the fast paced networking world. In providing service differentiation, the network traffic is divided into two categories, which are the low priority and the high priority traffic. Service differentiation is then made based on the two priority categories. Better attributes of the network is then been biased towards the high priority traffics. Focusing on DCF, several approaches had been made by past researchers to support QoS. In this section, several ideas to provide QoS in IEEE 802.11 are described, which involves refining the Contention Window (CW) values, discussed below.

Realizing the weakness of bandwidth reservation to provide QoS, Deng [7] rejects reservation schemes as it leads to a major drawback, which is when the source is reserved but unused, it is simply wasted. He proposed a method to support two priorities, high priority and low priority stations. Deng [7] proposed a scheme based on separation of CW. Originally, the random Backoff Interval (BI) is uniformly distributed between [0, 2^{2+i} - 1], in which i is the number of times the station attempted transmission of the same packet. In his scheme, the high and low priorities have random BI values uniformly distributed in intervals [0, 2^{2+i} /2 - 1] and [2^{2+i} /2, 2^{2+i} – 1]. Simulation results using Simscript reveal some improvement in delay and jitter for high priority traffic (voice and video).

On the other hand, Xiaohui [8] suggests the Modified DCF (M-DCF) scheme, which uses different values of CW_{min} and CW_{max} for service differentiation. Simulations of ad-hoc wireless LAN with 10 data stations and between 10 and 35 voice stations were performed. Voice service had CW_{min} of 7 and CW_{max} of 127 while data service had CW_{min} of 15 and CW_{max} of 255. The outcome illustrates that M-DCF decreases the total packet dropping probability and the dropping probability of voice packets as well as reduces the contention delay of both voice and data packets compared with DCF.

Another work done by Barry [9] and Veres [10] recommend using different values of CW_{min} and CW_{max} for different priorities, in which higher priority has lower CW_{min} and CW_{max} values than those of lower priority. Simulations of high priority traffic with CW_{min} between [8, 32] and CW_{max} = 64, and low priority traffic with CW_{min} between [32, 128 and CW_{max} = 1024] were performed. The outcomes show that the high priority and low priority traffic undergo different delay.

Meanwhile, Aad [11] introduces a differentiation mechanism based on CW_{min} separation, in which higher priority traffic has lower CW_{min} value. Simulations of a wireless LAN consisting of an access point (AP) and three stations with CW_{min} values of 31, 35, 50 and 65 were conducted with both TCP and UDP flows. The results reveal that for the same set of CW_{min} values, the differentiation effect is more significant on UDP flows than on TCP flows. The per-flow differentiation is introduced, in which the AP sends back Acknowledge (ACK) packets with priorities proportional to priorities of the destinations. In other words, the AP waits for a period of time which is proportional to delay from a destination before transmitting an ACK packet to the destination.

IV. Proposed Scheme

As discussed before, CW is a backoff mechanism for a mobilenode to avoid data collision, even after sensing the channel is in the idle state after the DIFS period. CW generates a random number within the range of CW_{min} and CW_{max}. In the original IEEE 802.11, there is no differentiation of CW_{min} and CW_{max} between a high priority and low priority traffic where the CW_{min} is 0 and the CW_{max} is 1023 [5] regardless the priority of the traffic. In this research, the value of CW_{min} and CW_{max} for both of the traffic is changed to support differentiation. The CW range is divided into two parts namely the first half and the second half. The first half will be assigned to the high priority traffics while the second half will be assigned to lower priority traffics. This is to ensure that high priority traffics will always be assigned to lower CW values. Meanwhile, the point where the CW is being separated into two halves is symbolized as **α**.

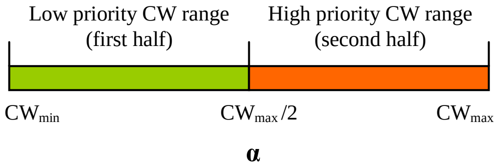

Figure 2. Contention Window Separation between high priority and low priority traffic

In Deng's [7] experiment, the CW is divided into two parts equally, which are the range of [0, 2^{2+i} /2 - 1] and [2^{2+i} /2, 2^{2+i} – 1]. However, in this research, the experiment of Deng will be further enhanced where several values of the **α** will be tested shown as in TABLE 1 below.

TABLE 1
THE VALUES OF THE CONTENTION WINDOW TO BE EXPERIMENTED

Proposed Contention Window Separation			
Experiment	**α** value	First half	Second half
A	256	[0, 256]	[256, 1023]
B	512	[0, 512]	[512, 1023]
C	768	[0, 768]	[768, 1023]

Each **α** value will be tested by conducting Experiment A to C. After the experiments had been done, the best **α** value will be determined by comparing the output of the proposed scheme with the output of the original IEEE 802.11g standard.

The CW can be configured under the MAC layer in NS-2 [12]. With the separation of CW range between high priority and low priority flows with the lower values of CW assigned to high priority traffics, the average delay of high priority traffic should be much lower than low priority traffic. This is because the high priority traffic will always get the chance to transmit data first compared to the lower priority traffic, as the waiting time is shorter. This will result on lower variation of delay which will lead to low values of jitter and a stable throughput.

V. SIMULATION SCENARIO

All simulation setup are configured using the Tool Command Language (TCL) in the TCL script of NS-2 [12]. In the simulation setup, the environment is set to radio links where channel type is configured as wireless channel.

Radio propagation models are used to predict the received signal power of each packet. Since IEEE 802.11 considers both the direct path and a ground reflection, the propagation model used in this simulation is the Two-Ray Ground Reflection Model.

This experiment is done as a per-based mobile communication. This means, each node can only transmit one type of data flow, which is whether a high priority data flow, or a low priority data flow. All of the QoS parameter readings are taken at the destination nodes.

Mobile stations are configured to use ad-hoc mode where the scenario consists of 16 mobile stations namely the N00 to N15. The first 8 nodes will be the sender while the other 8 nodes will be the receiver which will result to 8 pairs of traffic flow. Each traffic flow is named *fid 1* to *fid 8* respectively. Each sender will not have the same start time and stop time shown in TABLE 2. This is to see the effects of the throughput in different level of network loads.

TABLE 2
THE START TIME AND THE STOP TIME OF EACH FLOW ID

Flow id (fid)	Start time (second)	Stop time (second)
1	20	120
2	25	125
3	30	130
4	35	135
5	40	140
6	45	145
7	50	150
8	55	155

To simulate multimedia (voice and video) traffic, the node will generate a Constant Bit Rate (CBR) data flow whereas data traffic is simulated using File Transfer Protocol (FTP). In this experiment, the nodes of interest are Node 00 and Node 01 where both of the nodes will be using the configurations of the proposed scheme. Node 00 will generate high priority traffic of FTP and will be received by Node 08, while Node 02 will generate high priority traffic of CBR and will be received by Node 09. Other nodes will be using the standard configurations of the IEEE 802.11g.

In this network scenario, each node is in the network range of each other's where no hidden node exists. The bandwidth of the wireless channel is set to 54 Mbps, which represents the capacity of the 802.11g link.

In this research, two sets of experiments are made. The first set is the control experiment where the configurations and settings of the mobile stations and wireless environment are set to the default values. This set of control experiment is named the Null Experiment. The second set is the experiment where configurations have been made to follow the proposed scheme. The results of the proposed scheme will then be compared with the Null Experiment to determine the level of improvements or degradations.

VI. RESULT

In this experiment, two of the network flows, the *fid 1* and *fid 2* will be given focus as these two network flows constitutes the result of the proposed scheme.

The analysis of the result is computed using SPSS. The average variance value of the throughput is examined to determine the stability of the throughput. This is because variance will show the degree of the value that deviates from the mean value of the throughput which reflects the throughput stability.

In Experiment A, the **α** value is set to 256 where the first half of the CW is between 0-256 and the second half of the CW is between 256-1023. Results showed that there is a significant improvement towards throughput stability in *fid 1* and *fid 2* shown in Figure 3 and Figure 4 below.

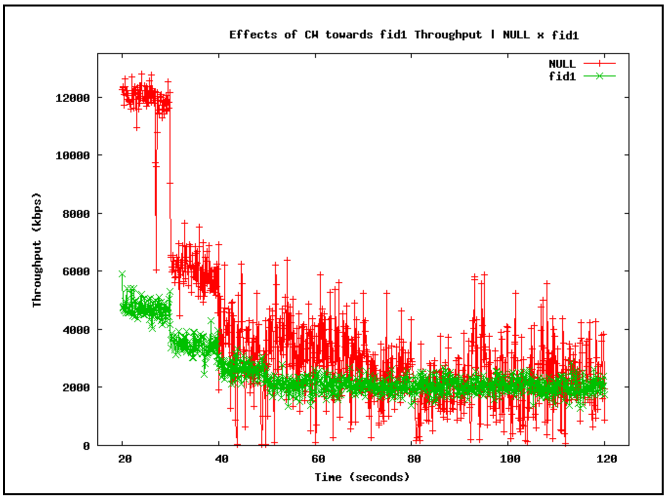

Figure 3. Effects of α = 256 towards throughput stability in *fid 1*

After the *fid 1* is configured to use the proposed scheme, the throughput can be seen to become more stable compared to the default configurations of the IEEE 802.11g shown in Figure 3.

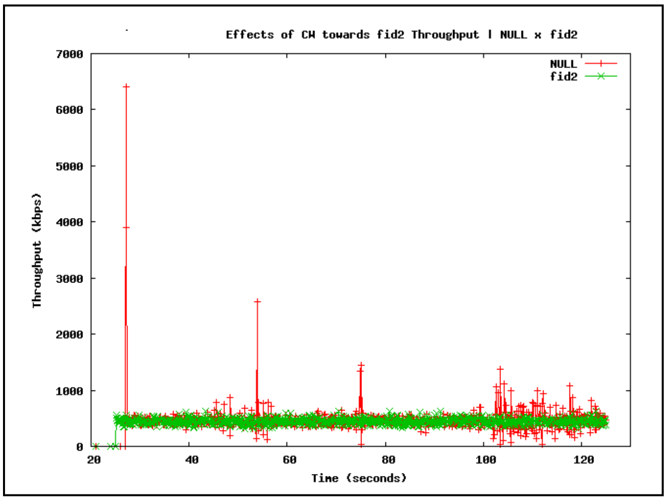

Figure 4. Effects of α = 256 towards throughput stability in *fid 2*

Fid 2 also showed significant improvements in throughput stability after it is being configured to use the proposed scheme. From Figure 4, the new values of the throughput do not deviates much from its mean value which means it has a more throughput stability.

The readings of each experiment, Experiment A, B and C are then computed in SPSS and the output can be summarized as below in TABLE 3 which represents *fid 1* and TABLE 4 which represents *fid2* respectively.

TABLE 3
THE EFFECTS OF DIFFERENT VALUES OF CW TOWARDS THROUGHPUT STABILITY IN FLOW ID 1

Flow id 1 (*fid 1*)		
Experiment	Variance	Improvements
Null	9853278.176	-
A	797388.494	91.907%
B	215563.360	97.812%
C	91804.536	99.068%

After computing the results in SPSS, the variance value of the throughput in Experiment A had been decreased by 9055889.68 which represent an improvement of 91.907% thus improving the throughput stability of the *flow id 1*. The improvement of the throughput stability increases to 97.812% in Experiment B where the **α** is 512. In Experiment C where the **α** is 768, further improvements of throughput stability is achieved where 99.068% of improvement is marked. This shows that the value of the throughput of the proposed scheme deviates from the mean in a smaller degree compared to the default configurations of the IEEE 802.11g.

TABLE 4
THE EFFECTS OF DIFFERENT VALUES OF CW TOWARDS THROUGHPUT STABILITY IN FLOW ID 2

Flow id 2 (*fid 2*)		
Experiment	Variance	Improvements
Null	75190.763	-
A	3099.478	95.878%
B	2930.413	96.103%
C	2753.590	96.338%

The result in *flow id 2* also shows significant improvements in throughput stability. In Experiment A, an improvement of 95.878% of variance is marked while in Experiment B where the **α** is 512, further improvements has been made where the throughput stability increases to 96.103%. Finally in Experiment C, an improvement of 96.338% of throughput stability has been achieved compared to the default configurations of the IEEE 802.11g.

From the findings, it is proved that using higher value of **α** (the point where the CW range is divided into two parts) will result on more stable throughput. This behavior can be explained as below.

When the **α** value becomes higher, the chances of lower priority traffic to be assigned shorter CW period will be slimmer. Therefore, the choices of the CW that can be assigned to low priority traffics is limited to only the high values of CW. This will lead to higher delay in low priority traffics which gives the advantage to the high priority traffic to always transmit the data first. Transmitting data continuously without interruption results to the low variation of packet arrival in high priority traffic, which reflects the stability of the traffic flow.

VII. Conclusion

The primary contribution of this paper focuses on detailed investigation on many of the DCF based access method of the wireless LAN by past researchers, focusing on the deploying method of the Contention Window. From the literature, most of them only consider throughput guarantee but not delay and jitter requirements, which is the crucial part in determining the throughput stability of the wireless network. These aspects of QoS are very important for video streaming and interactive video applications.

The simulation model proposed in this paper is derived from the literature which includes tuning the Contention Window to differentiate services between high priority and low priority traffic. From the findings and result of the experiments, it is viable that the author's approach to provide QoS in terms of throughput stability in wireless LAN is valid and applicable, thus improving the IEEE 802.11 to support Quality of Service.

VIII. Acknowledgment

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References

[1] D. Molta, "Wi-Fi Tales," *Network Computing*, pp. 44-62, 2004.

[2] Vannuccini, G. & Truong , H.L. *The IEEE 802.11e MAC for Quality of Service in Wireless LANs*. IBM Research, Zurich Research Laboratory, Switzerland, 2003.

[3] Pattara-Atikom, W. *Quality of Service Support in IEEE 802.11 Wireless Lan*. Ph.D Thesis, University of Pittsburgh.

[4] Cisco Systems, Inc. Cisco Announces New Independent Study Demonstrating Productivity Gains Achieved Through Wireless LAN Use, 2001. Viewed 14 January 2007, http://newsroom.cisco.com/dlls/corp_111201b.html

[5] IEEE Std. 802.11. Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, 1999.

[6] IEEE Std. 802.11g. IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. Amendment 4: Further Higher Data Rate Extension in the 2.4 GHz Band, 2003.

[7] Deng J. and Chang R. S. "A Priority Scheme for IEEE 802.11 DCF Access Method," *IECE Transactions on Communications*, vol. E82-B, No. 1, pp. 96-102, 1999.

[8] Xiaohui, J., Li J. and Guo F. "M-DCF: A MAC Protocol Supporting QoS in Ad Hoc Network," *The International Conference on Communication Technology WCC-ICT 2000*, vol.2, pp. 1718-1721, August 2000.

[9] Barry M., Campbell A. T, and Veres A. "Distributed Control Algorithms for Service Differentiation in Wireless Packet Networks," *Proceedings of the Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '01)*, pp.582 – 590, April 2001

[10] Veres A., Campbell A. T., Barry M. and Sun L.H. "Supporting Service Differentiation in Wireless Packet Networks Using Distributed Control". *IEEE Journal on Selected Areas in Communications* , Vol. 19, No. 10, October, 2001.

[11] Aad I., and Castelluccia C. "Remarks on Per-Flow Differentiation in IEEE 802.11". *European Wireless (EW)*, pp. 150-156, 2002.

[12] NS-2. Available at http://www.isi.edu/nsnam/ns (accessed 29.12.2006