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A Study on Contention Resolution Algorithms for Performance Enhancement in BWA

조선대학교 대학원

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이 논문을 공학석사학위신청 논문으로 제출함.

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컴퓨터공학과

Anup Thapa

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ABSTRACT

A Study on Contention Resolution Algorithms for Performance Enhancement in BWA

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In contention based channel access networks, whether wireless or wired, CRA (Contention Resolution Algorithm) plays an important role in an overall network performance indicator such as throughput, access delay, etc. In wireless networks, these days, OFDM (Orthogonal Frequency Division Multiplexing) has become a promising technique to support high speed transmission of broadband traffic, and OFDMA (Orthogonal Frequency Division Multiple Access) is regarding as the superior and preferred choice of multiple access. They seem to be key techniques for the future networks as well. Hence, with the precise goal of improving the network performance of such wireless networks, we investigate the performance enhancement in CRA which could be applied to a broad range of OFDMA based wireless networks. The detailed carried investigation makes a way for two new throughput and delay efficient CRAs, named CBELB (Combined Binary Exponential and Liner Backoff) and UBB (Utility Based Backoff), both of which are easily applicable to IEEE 802.16 based BWA (Broadband Wireless Access) systems.

CBELB is the hybrid CRA scheme which accounts on exponential increment of contention windows followed by the linear increment after few numbers of

previous transmissions. In our analyzed model of CBELB algorithm, for the first four initial collisions, the colliding SS increases its contention window size exponentially with the factor of 2, whereas in case of further successive collision, the SS increases the contention window size linearly until the maximum number of retransmission is reached. In case of successful transmission, or collision after maximum retransmission, SS starts from the beginning as the newly arrived SS. Implementation of CBELB algorithm in the OFDMA based BWA network reduces the average access delay for the successful ranging request transmission in comparison to legacy BEB. Medium access delay increased linearly with increase in number of SS in both BEB and CBELB algorithm but the increase in delay is comparatively less in CBELB algorithm.

UBB is the novel CRA which is based on the satisfaction of the SS on self selected backoff value in previous transmission/s. In UBB algorithm, whenever an active SS experiences a collision during ranging request transmission, it accomplishes its new contention window size based on the utility, satisfaction, upon its randomly selected backoff value on the previous transmission attempt. Higher the deferred backoff value lower will be the utility and vice versa. The key idea of this algorithm is to give less backoff window to the *SS* according to the given utility, if it has been waiting for longer duration in the previous trail and vice versa. The process is repeated unless the request is transmitted successfully, or until the maximum retransmission attempt is reached. UBB algorithm applied to OFDMA based BWA network reduces the average medium access delay for the successful request transmission in comparison to BEB. Even more, throughput for the lower offered load is higher in UBB than BEB.

요약

광대역 무선 통신에서 성능 향상을 위한 충돌 해소 알고리즘에 대한 연구

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유무선 경쟁 기반 채널 접근 네트워크에서 CRA (Collision Resolution Algorithm) 기법을 처리률, 접속 지연 등 전반적인 네트워크 성능에 대한 중요한 역할을 한다. 최근 OFDM 이 광대역 트래픽에 대한 고속 전송을 지원할 수 있는 방식으로 각광을 받고 있고, OFDMA 는 다중 접속 방식으로 선호되고 있다. 본 연구에서는 무선 네트워크에서 OFDM 기반 다양한 시스템에서의 성능을 향상시키고자 하는 목적으로 CRA 알고리즘의 성능 향상에 대한 연구를 수행하였다. CRA 알고리즘에 대한 분석적인 연구를 토대로 CBELB (Combined Binary Exponential and Liner Backoff), UBB (Utility Based Backoff)라는 처리률과 지연 특성에 효과적인 두 가지 새로운 알고리즘을 제시하였고, 이러한 알고리즘은 802.16 BWA 시스템에 적용하였다.

CBELB 는 초기 전송시도에서 지수적으로 경쟁 윈도우를 증가시키지만 몇 번의 시도 이후에는 선형적으로 증가시키는 복합형태의 CRA 기법이다. CBELB 알고리즘에 대한 우리의 분석적 모델에서는 초기 4 번째까지의 충돌에 대해서 충돌한 SS 는 자신의 경쟁 윈도우 사이즈를 2 의 제곱에 따라 지수적으로 증가시키고 이후 추가적인 충돌에 대해서는 최대 재전송 횟수에 도달할 때까지 경쟁 윈도우 사이즈를 선형적으로 증가시킨다. 전송에 성공한 경우 혹은 최대 재전송 횟수 이후의 충돌 발생 경우에 해당 SS 는 새로 진입한 SS 와 마찬가지로 처음부터 다시 시작한다. OFDMA 기반 BWA 에서 CBELB 알고리즘은 BEB

알고리즘에 비해 성공적인 레인징 전송에 있어서의 평균 접속 지연 시간을 단축시켰다. SS 증가에 따른 접속 지연은 BEB 와 CBELB 에서 같이 공통적으로 증가되지만, CBELB 에서 상대적으로 덜 증가한다.

UBB 는 이전 전송에서 선택된 백오프 값에 대한 만족도(satisfaction)에 기반한 새로운 CRA 알고리즘이다. UBB 알고리즘에서는 SS 가 레인징 전송 중 충돌을 경험할 때마다 이전 전송 시도에서 임의로 선택된 백오프 값에 대한 유틸리티 혹은 만족도 기반의 새로운 경쟁 윈도우 사이즈를 설정한다. 백오프 값이 클수록 유틸리티는 작으며 반대의 경우에도 동일하다. 이 방식의 핵심 아이디어는 이전 시도에서 오랫동안 기다린 SS 에 대해 주어진 낮은 유틸리티에 따라 SS 에 적은 백오프 경쟁 윈도우를 할당한다는 것이다. 전송이 성공할 때까지 혹은 최대 재전송 시도에 도달할 때까지 이 과정이 반복된다. OFDMA 기반 BWA 네트워크에 적용된 UBB 알고리즘은 BEB 알고리즘에 비해 평균 접속 지연이 적으며, 시스템의 부하가 작은 경우 처리률도 BEB 에 비해 UBB 가 더 높았다.

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Acronyms

BEB	Binary Exponential Backoff
BS	Base Station
BWA	Broadband Wireless Access
CBELB	Combined Binary Exponential and Linear Backoff
CDMA	Code Division Multiple Access
CRA	Contention Resolution Algorithm
Cw	Contention Window
DIDD	Double Increase Double Decrease
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
EIED	Exponential Increase Exponential Decrease
IEEE	Institute of Electrical and Electronics Engineers
MAC	Medium Access Control
MILD	Multiplicative Increase Linear Decrease
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PN	Pseudo Noise
SS	Subscriber Station
TBEB	Truncated Binary Exponential Backoff
TDMA	Time Division Multiple Access
UBB	Utility Based Backoff
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network

I. Introduction

A. Research Overview

In shared channel access networks, either wireless or wired, one of the key issues is to distribute the available resources in every effective way among the several communicating entities. Sharing of the same resources between those active entities can cause collision among themselves. Thus the contention based MAC (Medium Access Control) protocols have been extensively studied for shared medium access networks. Among those protocols CRA (Contention Resolution Algorithm) comes as a significant one. In order to effectively distribute the available resources and minimize the collision, diverse CRA schemes have been proposed so far. Random backoff technique is one of the schemes in CRA in which the entity upon collision waits for the random period of time before its next transmission. This random period is referred to as retransmission delay, waiting time, or simply backoff. In such a scheme, the backoff algorithm controls the backoff interval dynamically. In general, collision probability is independent of the number of retry times but depends on number of transmitting entities. An efficient CRA is that which grants transmission opportunity to only one active entity at a time by suspending other entities and keeping them in backoff state without delay, loss of throughput, and unfairness together with simplicity of operation.

Whether a network is wired or wireless, CRA is equally important; however, it offers more challenges when designing or selecting the efficient one specifically for wireless networks. Limited spectrum resources, network complexity, open and dynamic channel architecture, and geographically distributed users are some basic characteristics which demand the CRA to be more robust in wireless medium than in wired medium. Hence, it becomes very important to study and understand the role of CRA in wireless media. Thus the study and the development of the novel CRA which can enhance the throughput/delay performance of the network is one of the major considerations of the present communication world. In addition, the diverse application domains like fixed wireless access, WiFi backhauling, nomadic internet access, and high data rate access with seamless sessions are in the for front in the present context. Furthermore, in recent years several last mile high speed technologies have been explored to provide wireless internet access and real time multimedia services to end users. They are representing the revolution towards the BWA (Broadband Wireless Access) by dominating the legacy systems like fiber optic links, coaxial system using cable modem system as in DOCSIS (Data Over Cable Service Interface Specification), and DSL (Digital Subscriber Line). On the other hand, with the evolution of the BWA, more users with the demand of sophisticated applications with different QoS (Quality of Service) parameters are simultaneously emerging. Therefore, next generation wireless communication system will be required to provide flexible and easy broad band access for high speed communications and should support varieties of services utilizing advanced multiple access scheme OFDMA (Orthogonal Frequency Division Multiple Access). Thus the available resources are required to be distributed effectively in order to fulfill the customer’s demand of advanced and reliable services. At a same time, the resources should be highly utilized denying any wastage. The main network performance degradation of most of the network comes from packet collisions and the wasted idle slots due to backoff in each contention cycle. Thus, in this context, the CRA can play an effective role in distribution of the resources in any network which employ backoff algorithm for the contention resolution in shared channel access.

B. Research Objective

This thesis entailed the study and proposal of new CRAs to minimize the drawbacks that the existing legacy algorithm BEB (Binary Exponential Backoff) holds. From the widely available literatures, we can easily find out that different types of CRAs have been proposed so far for the contention resolution in wireless networks. BEB, EIED (Exponential Increase Exponential Decrease) [1], MILD (Multiplicative Increase Linear Decrease) [2], DIDD (Double Increase Double Decrease) [3], Logarithmic Based Backoff [4] are only few examples of such algorithms. However, these varieties of algorithms have been developed and proposed to suit the different applications accordingly, where various tradeoff factors have been considered for each of them. Among these CRAs, BEB is one of the widely implemented schemes in diverse wireless networks specifically in IEEE 802.11 and IEEE 802.16 based networks. BEB is more famous and widely accepted for its simplicity and its property of offering high performance in low traffic scenarios; however, its performance falls down rapidly with increase in the number of SSs (Subscriber Stations: Communicating Entities) [5]. In addition, as the backoff value in BEB algorithm has uniform random distribution and each SS starts from the initial state by resetting the contention window size to minimum after its successful transmission, the SS with poor channel condition often suffers from increasing the contention window size exponentially with resulting to compete for the same channel with the other SSs having small backoff values. Due to this property, there is high possibility of the channel being captured (known as capture effect) by the active SSs with good channel quality. Consequently, the BEB algorithm is often criticized as unfair backoff algorithm [6].

Hence the primary objective of this research was to develop an idea in order to overcome the limitations of the BEB and enhance the performance of the networks in terms of throughput and delay. Since the simplicity and easily deployable properties are the key and basic required parameters when designing the new algorithm, the secondary but equally precise objective was to develop an algorithm without any additional complexity.

These objectives are accomplished via the development, analysis, and the proposition of the algorithms, namely, CBELB (Combined Binary Exponential and Linear Backoff) and UBB (Utility Based Backoff). Their performance evaluation depicts their higher efficiency in comparison to BEB.

C. Research Layout

Two new backoff algorithms termed CBELB and UBB have been proposed to enhance the performance of the network in terms of network throughput and average medium access delay. For the analysis, OFDMA based BWA, IEEE 802.16 international standard based system has been considered.

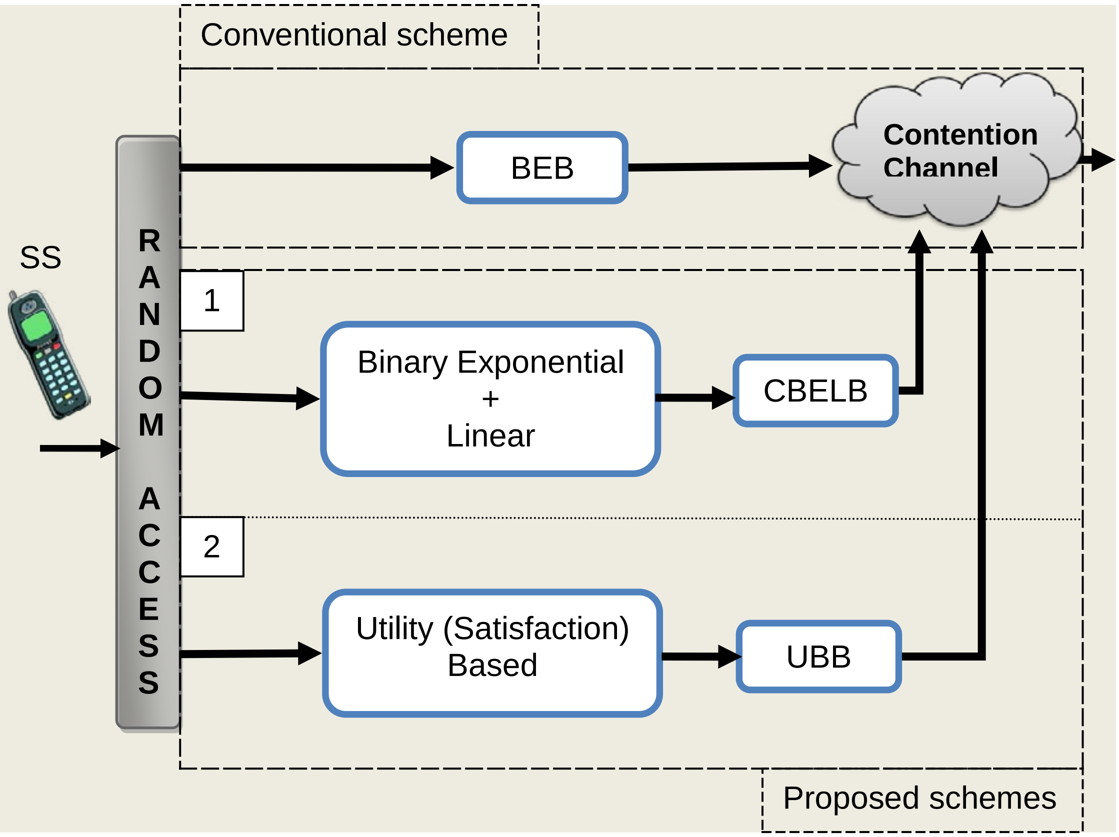

Figure 1- 1: Diagrammatic representation of carried research

D. Thesis Contribution

The characteristics parts of the carried research work are summarized under the title of the thesis contribution. They are as follows.

- CBELB, a new backoff algorithm, can be viewed as the simple but the modified version of the traditional BEB. CBELB inserts the linear property while selecting the contention window size in addition to the initial exponential increments after certain number of previous transmissions. Implementation of CBELB algorithm in the OFDMA based BWA network reduces the average access delay for the successful ranging request transmission in comparison to legacy BEB algorithm.
- UBB can be viewed as the simple, novel, and robust algorithm which can increase or decrease the contention window size according to the level of the satisfaction of an user upon its own selection of the backoff value in previous transmission/s. UBB algorithm applied to OFDMA based BWA network reduces the average medium access delay for the successful request transmission in comparision to BEB. Even more, throughput for the lower offered load is higher in UBB algorithm than BEB.

E. Thesis Organization

The content of this thesis is organized in modular chapters. Chapter 2 is devoted to brief overview of BEB algorithm for bounded and unbounded models. Related works are also included in this chapter along with the description of the limitations of the BEB. In chapter 3, proposed CRAs, CBELB and UBB are presented. Over view of the OFDMA based BWA system and the collision probability determining factors in such a network is also covered in this chapter. Then the last chapter concludes the thesis with wrapping text for the summary of the carried research and possible future works.

II. Binary Exponential Backoff Algorithm

A. Introduction

According to the definition, exponential backoff is an algorithm that uses feedback to multiplicatively decrease the rate of some process, in order to gradually find an acceptable rate [7]. BEB is one of the exponential backoff algorithms which decrease the rate of the transmission process of any SS by the factor of 2 in every collision. This decreasing factor is also sometimes referred as a penalty factor in literatures. BEB is one of the widely used backoff algorithms in the wireless/wired networks. It has over 3 decades of research history. It has been accepted as a de facto standard contention resolution scheme in different networks like Ethernet, WLAN (IEEE 802.11), and WMAN (IEEE 802.16). Thus BEB is the preferred choice for contention resolution these days.

In BEB, every time SS experiences collision, Cw (Contention Window) size is enlarged by doubling the previous one. Cw is the window size from which the backoff value is randomly selected. With the increase of the retransmission attempt, the span of the backoff delay (waiting time) increases according to 2-exponential (Figure 2-1). In order to avoid the contention window from growing too large, two bounds on the Cw are defined: $Cw^{\max}$ (maximum contention window) and $Cw^{\min}$ (minimum contention window). $Cw^{\max}$ depends upon the number of times it has experienced the collision while $Cw^{\min}$ is always fixed. Thus the backoff value for a user is selected randomly within the range of $Cw^{\min}$ and $Cw^{\max}$. The Cw goes back to the initial minimum value after the successful transmission.

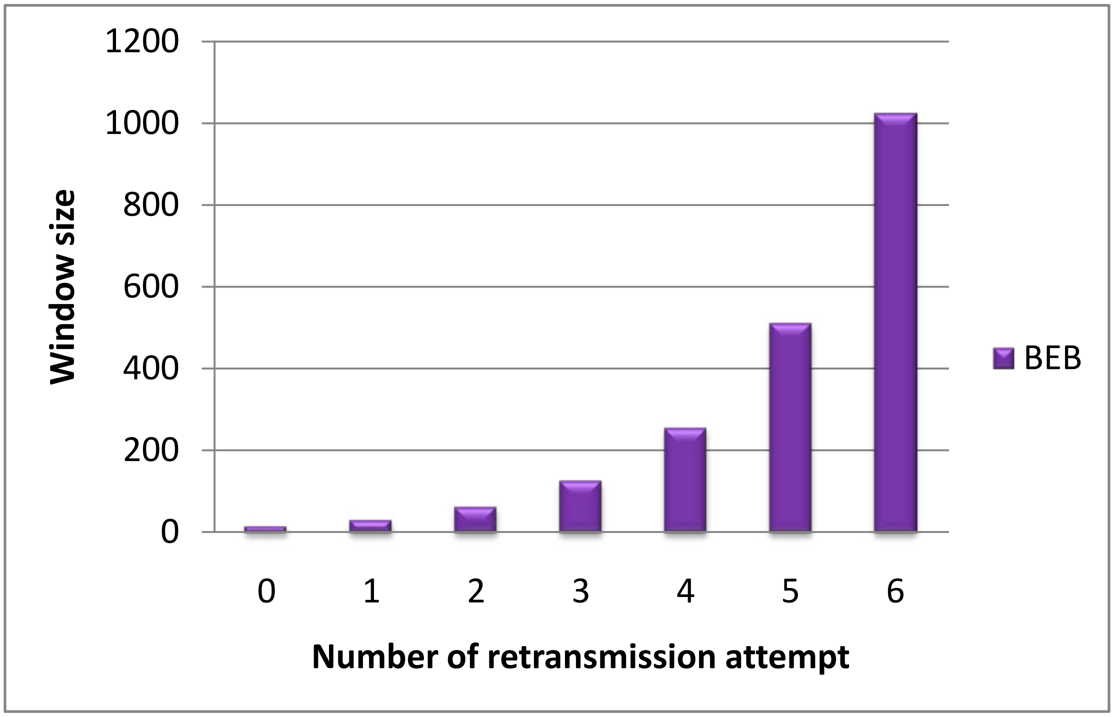

Figure 2- 1: Increment of maximum waiting time with respect to number of transmission attempt in BEB.

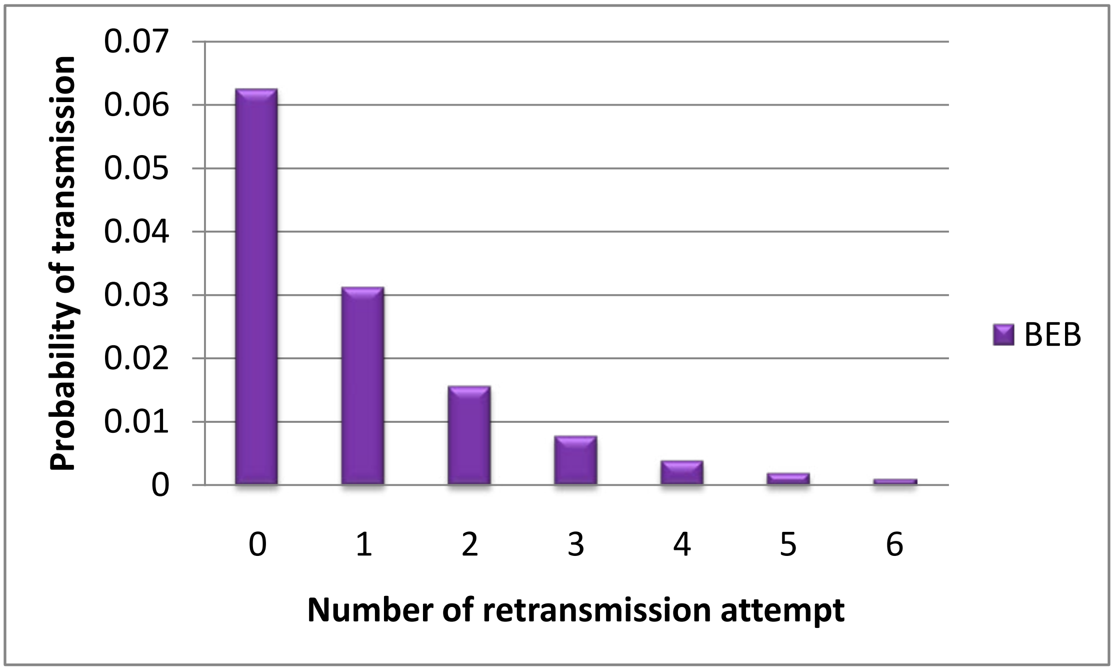

Figure 2- 2: Decrement of the probability of transmission with respect to the number of transmission attempt in BEB.

Let i be the number of state. For unbounded (infinite) model, $0 \le i \le \infty$. Whereas, for the bounded model (i.e truncated binary exponential backoff) $0 \le i \le M$. During initial network entry SS enters into state $i = 0$. SS can transit the states upto state M in bounded model while it can transits upto infinite state if the model is infinite one by increasing the value of i by 1 in every successive collision. In any state i, SS randomly selects the backoff value from the range of $Cw^{\min}$ and $Cw_i^{\max}$, where $Cw_i^{\max}$ represents the maximum contention window value for state i. Once the backoff value is selected, SS waits till that value is deferred to 0 before its next transmission. On the very next opportunity it transmits the request. Once there is collision, i is increased by 1. In case of successful transmission, SS starts the next procedure again from the initial state, $i = 0$. Assuming$Cw^{\min} = 2^4 - 1$, BEB algorithm can be defined as

1. On entry: $Cw_0 = [0 - (2^4 - 1)]$, and $k_0 = rand\,\mathrm{int}[0 - (2^4 - 1)]$, where randint is a function to select random integer value, Cw_0 is contention window size on the first entry , and k_0 is backoff value selected randomly in the state $i = 0$. If Cw_i is a contention window for the state i, and k_i is the randomly selected backoff value, then $k_i = rand\,\mathrm{int}[Cw_i]$.
2. On collision: $Cw_i = [0 - (2^{i+4} - 1)]$
3. On success: $Cw_s = Cw_0$
4. If bounded model then after state M: $Cw_{M+1} = Cw_0$

Figure 2-3 and Figure 2-4 represent the contention resolution process using the BEB algorithm with maximum number of contention window in each state for unbounded and bounded model, respectively.

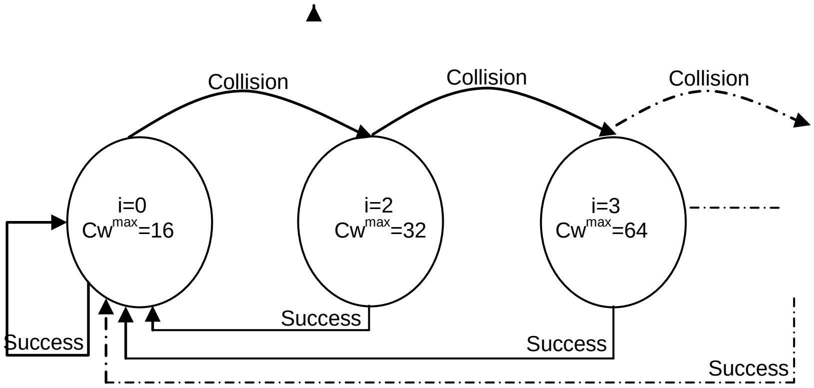

Figure 2- 3: Contention resolution process with maximum contention window size for unbounded model.

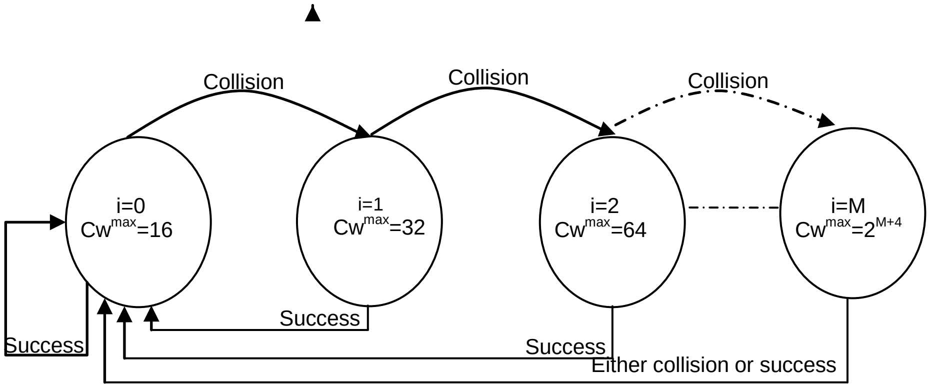

Figure 2- 4: Contention resolution process with maximum contention window size for bounded model.

B. Related Work

As mentioned earlier, BEB is famous for its simplicity. However, in contrast to its popularity, it has been equally criticized. Already much research work has been done to model and study the performance and the stability of BEB. Most of the papers have studied its stability in terms of effect on network performance as the offered load increases. The results that have been received from different research appear to be contradicting each other. Some authors claim that it is stable while some say it is not. However, the result of analysis highly depends upon the mathematical model they have used. In [8] and [9] , for any infinite node model ($n = \infty$), it has been shown that BEB is unstable for arrival rate greater than 0.693 and strongly stable for arrival rate less than 0.567 , while in [10], the authors have shown the protocol is instable for any non zero arrivals. In [11], using the modified finite node model, authors have shown that BEB is stable for sufficiently small arrival rates, while in [12], it has been claimed that it is stable for the infinite model.

Apart from the study of the stability and performance of the BEB, in order to overcome the limitations of the BEB and enhance the network performance by resolving the contention, different authors have proposed different algorithms like EIED, MILD, DIDD, Logarithmic Based Backoff etc. These algorithms have been developed to suit the different applications where each of them considers different tradeoff factors. Although these innovative algorithms have been proposed with objective to enhance the network performance, very few of them can satisfy simultaneously all desirable properties such as high throughput, low delay, and good fairness while maintaining the simplicity of implementation in real wireless networks.

In EIED, whenever a request transmitted from a SS is involved in a collision, the contention window size for the SS is increased by backoff factor r_I, and the contention window for the SS is decreased by backoff factor r_L if the SS transmits a packet successfully [1]. In MILD, contention window size is multiplied by a factor of 1.5 on a collision but decrease by 1 on successful transmission [2]. While, in case of DIDD, Cw is reduced by half on every successful transmission and doubles in every collision. Logarithmic based backoff use logarithmic based increment of the contention window in every collision and resets the contention window into minimum after the successful transmission.

All these above mentioned algorithms are proposed for IEEE 802.11 DCF networks. However, later in [5], authors extend and proposed EIED for BWA. In

[5], authors proposed EIED for the enhancement of IEEE 802.16 WMAN ranging performance. IEEE 802.11 DCF is based on a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique. In IEEE 802.11, CRA is used for the contention resolution for data packet transmission, while in BWA, IEEE 802.16, it is used for contention resolution in contention based ranging request transmission.

In [5], as mentioned earlier, EIED has been proposed to enhance the performance of the initial ranging request transmission in IEEE 802.16 WMAN. The number of retries times for the successful ranging transmission reduces when using EIED in compare to BEB. However, its performance degrades when the network load is light because it takes quite long time to recover from the backoff caused by occasional collisions. In addition, when the number of active SS changes from high to low, EIED cannot adjust its Cw fast enough due its exponent decrease mechanism, which results in additional delay.

C. Limitations of BEB

In BEB scheme, as mentioned earlier, the Cw size is set to be initial minimum value upon successful transmission whereas it increases by 2-exponential on collision. Thus in BEB, often the SS with good channel characteristics receives more favor. As the backoff value in BEB is uniform random distribution, a SS with poor channel condition often suffers from large delay and unfairness when the SS fails to transmit a request resulting increase the contention window size exponentially and competing for the same channel with other SSs having same backoff value. Because of this property, there is high possibility of the channel being captured (known as capture effect) by the active SSs with good channel quality. Consequently, the BEB algorithm is often criticized as unfair backoff algorithm.

III. Proposition of Modified CRA for Performance Enhancement in OFDMA based BWA Network

A. Introduction

For the broadband wireless data network, compared with traditional access technologies such as TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access), OFDMA (Orthogonal Frequency Division Multiple Access) is superior. OFDM (Orthogonal Frequency Division Multiplexing) is one of the applications of a parallel transmission scheme which can combat hostile frequency selective fading environment. The robustness against frequency selective fading is very attractive, especially for high speed data transmission. Therefore, it is well understood that OFDM based wireless systems will provide the solutions for future generation wireless communications [13]. OFDM scheme has matured well through research and development for high rate WLANs and terrestrial DVB (Digital Video Broadcasting) and already been proposed for IEEE 802.11a Wireless LAN and IEEE 802.16 Wireless MAN. Compared with single-carrier multiple-access systems, OFDMA offers increased robustness to narrowband interference and allows straightforward dynamic channel assignment. Other advantages of OFDMA include its MIMO friendliness and ability to provide superior QoS (Quality of Service). As a result, OFDMA is the preferred choice for multiplexing technique these days, and it will be the backbone of the future BWA. Therefore, next generation wireless communication system will be required to provide flexible and easy broad band access for high speed communications and support varieties of services utilizing advanced multiple access scheme OFDMA.

Multiple Accesses, sharing of the same channel by multiple users, can cause collision. Therefore, one of the key issues in wireless communication is to distribute the access channel in very effective ways among the several geographically distributed users. To share access channel, many schemes have been studied and proposed so far. However, the note worthy point is that wireless channel is shared medium and is always interference limited. Collision in the data channel can lead serious data loss. Therefore, in OFDMA based BWA network, there is a provision of separate contention based channel access scheme for adjustment parameters exchange, while contention free data channel access scheme for the data transmission after the bandwidth grant [14-15].

The contention based information exchange is called ranging. Ranging process use CDMA type code transmission to negotiate the synchronization parameters like time, power, and frequency between SS and BS (Base Station). Though possibility of collision is only in the ranging channel, nevertheless, it plays a vital role in the overall network performance. In OFDMA based BWA network, collision results if two or more than two SSs transmit the same code in same frame. However, the number of available ranging codes, the applied contention resolution scheme, and the number of SS in the network determine the collision probability.

Therefore, in order to effectively distribute the available resources and minimize the collision, diverse CRA schemes have been proposed. Random backoff technique is one of the schemes in CRA, in which users upon collision wait for the random period of time before next transmission. This random period is referred to as retransmission delay or simply backoff. In such scheme, the backoff algorithm controls the backoff interval dynamically.

BEB algorithm is one of the widely used contention resolution schemes in shared channel access. Furthermore, BEB has been accepted as de facto contention resolution schemes in the dominating networks like Ethernet, WLAN or WMAN. In OFDMA based BWA network as well, BEB is the preferred choice and has been accepted.

B. Ranging

In OFDMA based BWA (IEEE 802.16) channel architecture, the basic transfer unit is a frame. Frame is divided into uplink and downlink sub-frames. The initial few uplink symbols are separated for the ranging channel and the rest for the data channel. IEEE 802.16 adapts 1024 orthogonal subcarriers, among which 864 subcarriers are used as user tone. The first 3-OFDMA symbols of the uplink sub frame are separated for the ranging process.

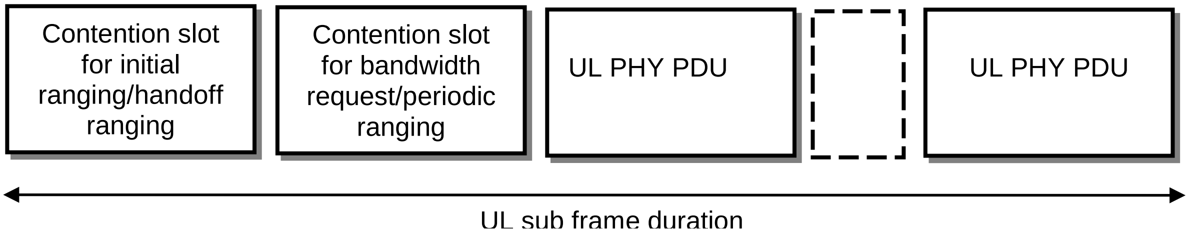

Figure 3- 1: OFDM PHY uplink sub frame.

Ranging is a part of the admission control procedure in OFDMA based BWA network. Basically there are four types of ranging process defined: initial ranging, periodic ranging, bandwidth request ranging, and handoff ranging [13-14]. Initial ranging is the process of acquiring correct timing offset and power adjustment at the initial network entry while periodic ranging is for periodically adjustment. Handoff request transmission and band width request transmission can also be provisioned with ranging code.

The available orthogonal PN (Pseudo Noise) codes are subdivided into sub-sets and are assigned to each different type of ranging, such that the BS can determine the purpose of the received code by the subset to which the code belongs. For the initial ranging request transmission, SS randomly selects a PN code from a set of code available for the initial ranging and transmits it to BS. After the transmission, it waits for the ranging response message from BS.

Figure 3- 2: Ranging request procedure.

If the message is transmitted successfully without collision, the SS will receive ranging response message from BS. The ranging response message consists the information regarding timing synchronization, power adjustment, and the message to-continue. Upon receiving the ranging response message, SS continues the same process from beginning with adjusted parameters using new ranging code.

For transmitting the ranging request code in random access channel, SS uses TBEB (Truncated Binary Exponential Backoff) algorithm. Truncation supplemented in the BEB restricts the increment of Cw after certain number of previous increments. In the random access channel, collision occurs if two or more than two SSs transmit same code in same slot. In case of the collision, each time, the collided SS randomly selects a backoff value from the range of $Cw^{\min}$ and $Cw^{\max}$ according to TBEB algorithm and waits till that value deferred to 0. This random value is the number of transmitting opportunities that the SS must give up before retransmitting the request.

C. Mathematical Analysis of the Ranging Procedure in BWA Network

For the mathematical analysis of the ranging procedure in BWA Network, we have made following assumptions.

- There is N number of SSs inside a cell.
- There is no coordination (no broadcast) from the BS in order to select the contention window size.
- One ranging code transmission opportunity in one frame.

Let i be the number of states, $0 \le i \le M$. Here M is the maximum number of state which is supplied for the truncation. During initial network entry SS enters into state $i = 0$. SS can transit the states up to state M in bounded model while it can transits up to infinite state if the model is infinite one by increasing the value of i by 1, in every successive collision. In any state i, SS randomly selects the backoff value from the range of $Cw^{\min}$ and $Cw_i^{\max}$, where $Cw_i^{\max}$ represents the maximum contention window value for state i. Once the backoff value is selected, SS waits till that value is deferred to 0 before its next transmission. On the very next opportunity it transmits the request. Once there is collision, i is increased by 1. In case of successful transmission, SS starts the next procedure again from the initial state, $i = 0$.

We assume SS_i as the i^{th} state of the SS. After sending the request at state i, SS can enter either into next state $i+1$ (i.e. SS_{i+1}) or the state 0 (i.e. SS_0) depending upon the collision or success of the transmitted request, respectively. After the M^{th} time collision the SS discards the contention resolution process and starts the ranging process as per the newly arrived SS from beginning.

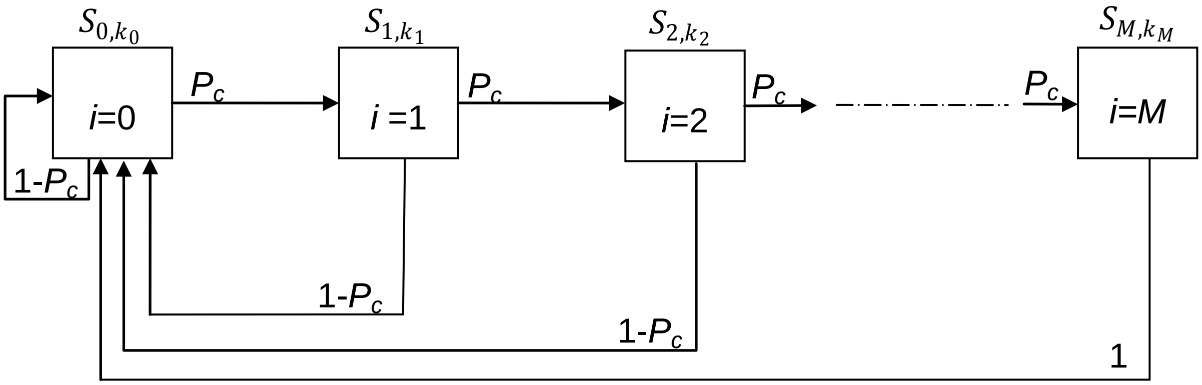

Figure 3- 3: State transition diagram for markov chain analysis.

If we assume the SS is in steady state with the probability of collision P_c, from 1-D markov chain analysis, SS_i is the chain with the transition probabilities $P_{i,z}; i, z = 0,1,2,...,M$. The transition probabilities can be represented as,

$$P_{i,0} = \Pr\{SS_{i+1} = 0 \mid SS_i = i\} = 1 - P_c, \tag{3-1}$$

$$P_{i,i+1} = \Pr\{SS_{i+1} = i+1 \mid SS_i = i\} = P_c, \tag{3-2}$$

$$P_{M,0} = \Pr\{SS_0 = 0 \mid SS_M = M\} = 1. \tag{3-3}$$

If we take P_i as the relative frequency to enter the state ◢ [16], we can define P_i

$$P_i = \frac{(1-P_c)P_c^{\,i}}{1-P_c^{\,(M+1)}}. \tag{3-4}$$

P_i implies the probability to succeed the previous state and enter into the next state. However, the average time SS stays in state ◢ is different for each state. The random integer selected with the applied backoff algorithm determines the stay of SS inside the state ◢. Therefore, if the SS enters into state ◢, it generates an integer random variable, k_i, between 0 and $Cw_i^{\max} - 1$ and waits till that value deferred to 0. The backoff value is decremented frame by frame (as there is only one transmission opportunity per frame). After waiting for k_i transmission opportunities, SS retransmits the ranging request. Thus the next state of SS is determined with success or failure of the request send. Consequently, SS stays in state ◢for $k_i + 1$ frame.

Let S_{i,k_i} be the probability of distribution of SS inside the state ◢with the backoff value k_i. Likewise, let S_i be the probability of distribution of SS over the state ◢. S_i is the function of P_i and $Cw_i^{\max}$ [11]. Then,

$$S_i = \frac{P_i k_i}{\sum_{i-0}^{M} P_i k_i}. \tag{3-5}$$

Let

$$K = \sum_{i=0}^{M} P_i k_i. \tag{3-6}$$

From (3-5) and (3-6)

$$S_i = \frac{P_i k_i}{K}. \tag{3-7}$$

Let $\Pr\{t = k_i \mid i\}$ be the conditional probability that SS's backoff timer ◢will have value k_i, given that the SS is in state ◢. Since $\sum_{k_i}^{Cw_i^{\max}-1} \Pr\{t = k_i \mid i\} = 1$, it follows

$$S_i = \sum_{K_i=0}^{Cw_i^{\max}-1} S_i \Pr\{t = k_i \mid i\}, \tag{3-8}$$

$$Si = \sum_{k_i}^{Cw_i^{\max}-1} S_{i,k_i}. \tag{3-9}$$

As the backoff timer decreased by one in every frame S_{i,k_i} satisfies

$$S_{i,k_i} = S_{i,Cw_i^{\max}-1}(Cw_i^{\max} - k_i), \tag{3-10}$$

Where $k_i = 0,1,2,\ldots,Cw_i^{\max} - 1$. Substituting (3-10) in (3-9), it can be shown that

$$S_{i,Cw_i^{\max}-1} = \frac{S_i}{k_i Cw_i^{\max} - 1} = \frac{P_i}{KCw_i^{\max}}. \tag{3-11}$$

When SS is in the state ◢ with backoff timer value k_i, it must wait until the backoff timer decreased to 0. Therefore $S_{i,0}$ is the probability that SS is in the state ◢, its backoff timer has expired and it will transmit the request. It leads

$$S_{i,0} = \frac{P_i}{K}. \tag{3-12}$$

If we take P_t as the probability that the given SS will transmit in an arbitrary time instance, P_t equals the sum of probability of all the mutually exclusive events. Then

$$P_t = \sum_{i=0}^{M} S_{i,0} = \sum_{i=0}^{M} \frac{P_i}{K}. \tag{3-13}$$

From eq. (3-4) and (3-13), if we assume P_c is known, we can calculate P_t in terms of P_c; $0 \le P_c \le 1$. Similarly if we assume P_t is known, then we can calculate P_c for the given number of CDMA ranging code. The ranging code will experience collision if two or more SSs transmit the same code at the same time. If there are C number of CDMA codes available for N number of SSs, the conditional probability that one CDMA code, suppose C_1, will experience collision can be expressed in terms of P_t as [5]

$$P_c = 1 - \sum_{n=0}^{N-1} \Pr\{n \text{ SSs Tx CDMA codes other than } C_1\},$$

$$= 1 - \sum {}_{N-1}C_n \left(P_t \tfrac{C-1}{C}\right)^n \left(1 - P_t\right)^{N-1-n},$$

$$= 1 - \left(1 - \tfrac{P_t}{C}\right)^{N-1}. \tag{3-14}$$

From (3-14),

$$P_t = C\left(1 - (1 - P_c)^{\frac{1}{N-1}}\right). \tag{3-15}$$

Thus P_t in eq. (3-15) gives the probability of transmission of a code in an arbitrary frame when there are N SSs in the system.

1. Ranging Code Collision Probability in OFDMA based BWA Network

To demonstrate the ranging code collision probability in OFDMA based BWA network, we considered the markov chain model as shown in Figure 3-3, and after deriving the required mathematical relations (section III-B) we simulate our model using MATLAB. Simulation is run for 100 times and average values are taken.

Figure 3-4 depicts the curves of probability of collision and probability of transmission according to eq. (3-13) and (3-15). In the figure, the downward, 'o' marked line represents the probability of transmission of a SS in an arbitrary frame according to the given probability of collision. Rest of the lines represent the probability of transmission in a frame for the given probability of collision while there are 10, 20, 50, and 100 SSs in the network with available CDMA code C = 4 and $Cw^{\min} = 16$, respectively. If all SSs in steady state has the same backoff parameters, they will all see the same average collision probability, P_c,

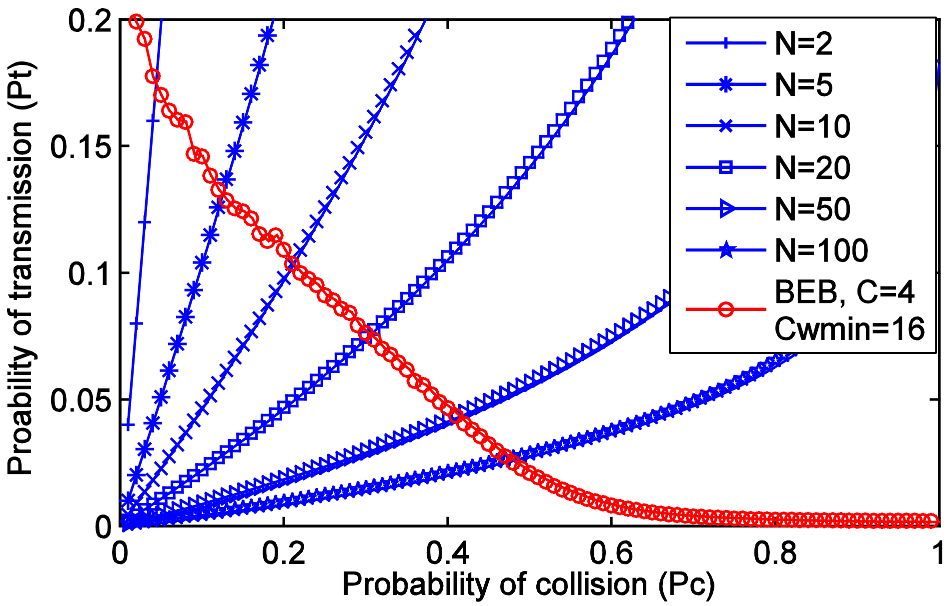

Figure 3- 4: Plot of probability of collision and probability of transmission for eq. (3-13) and eq. (3-15), when available number of ranging code is 4, minimum contention window size is 16, and maximum contention window size is fixed at 1024.

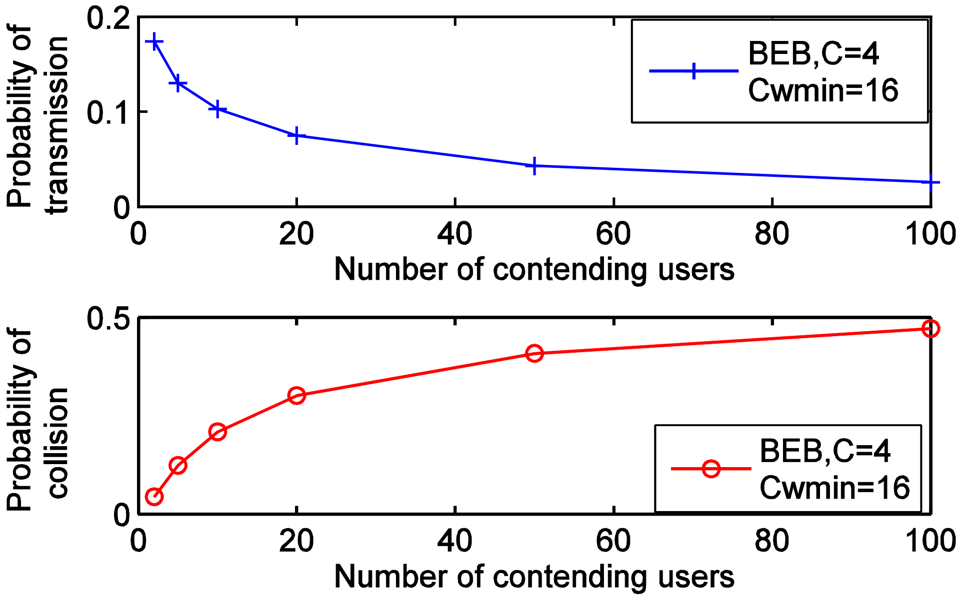

Figure 3- 5: Plot of the probability of collision and probability of transmission from fixed point analysis in Figure 3-4.

and hence they will have same transmission probability, P_t [17]. Thus from fixed point analysis, i.e. from intersection points in Figure 3- 3, we can get P_c and P_t of a SS during an arbitrary frame time.

Figure 3-5 shows the plots of P_c and P_t, obtained from the intersection points in Figure 3- 4, with respect to number of contending users. From the lower window of Figure 3-5, the higher number of contending users increases the probability of collision. From upper window of Figure 3-5, the higher the number of contending number of users is the lower the probability of transmission. It is because high probability of collision causes the higher backoff value which leads to the lower probability of transmission.

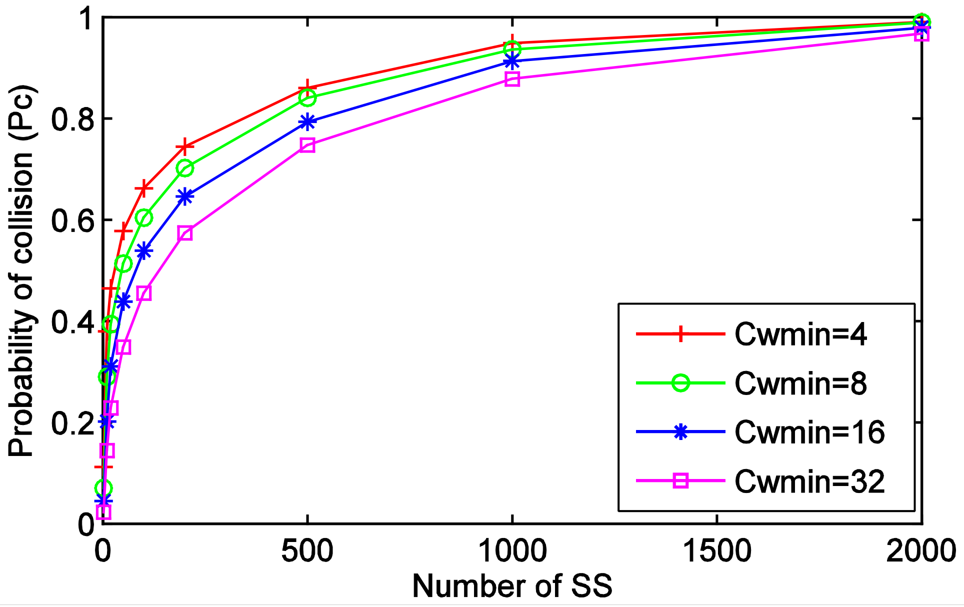

Figure 3- 6: Plot of the probability of collision with varying $Cw^{\min}$ **, when** $C = 4$ **and** $Cw^{\max} = 1024$.

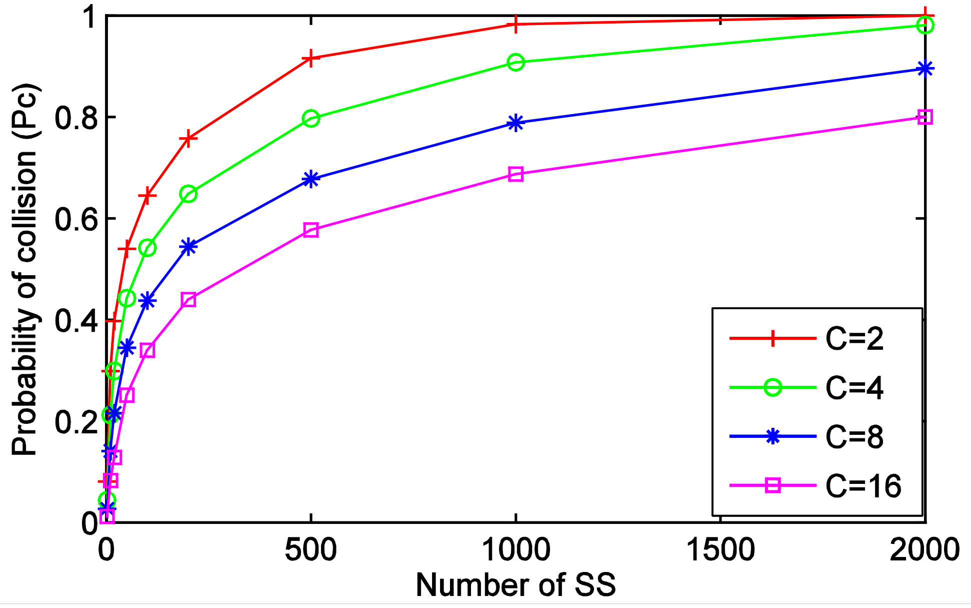

Figure 3- 7: Plot of the probability of collision with varying C**, when** $Cw^{\min} = 16$ **and** $Cw^{\max} = 1024$. **.**

Figure 3-6 depicts the probability of collision with respect to the number of contending users when $Cw^{\min}$ varies. Probability of collision goes up with increase in the number of contending users. Higher number of SSs tries to access the same channel which obviously increases the probability of collision. From Figure 3-6, lower the $Cw^{\min}$ higher is the probability of collision, because lower $Cw^{\min}$ resembles small backoff time in the beginning which ultimately increases the transmission rate, or in other words collision probability.

The collision probability with respect to the number of users when number of available CDMA code varies is presented in Figure 3-7. Probability of collision increases with number of users but higher the number of available codes lower is the probability of collision because with higher number of available code the probability of transmitting the same code by rest of the SS reduces.

Table I and II shows the maximum number of users per frame that offer guaranteed probability of collision, γ, for varying $Cw^{\min}$ and C, respectively. If we pay interest in probability of collision 20%, i.e 80% probability of successful transmission in a frame, is requirement in the system then 5, 7, 10, and 17 user's

Table 3- 1: Number of users with guaranteed probability of collision, γ, during $Cw^{\min}$ change.

γ	SS max. when $Cw^{\min} = 4$,	SS max. when $Cw^{\min} = 8$	SS max. when $Cw^{\min} = 16$	SS max. when $Cw^{\min} = 32$
0.1	0	3	5	7
0.2	5	7	10	17
0.3	8	11	19	38

Table 3- 2: Number of users with guaranteed probability of collision, γ, during code change.

γ	SS max. when C=2	SS max. when C=4	SS max. when C=8	SS max. when C=16
0.1	3	5	7	14
0.2	6	10	18	38
0.3	10	19	39	77

simultaneous transmission can be accepted by varying the $Cw^{\min}$ by 4, 8, 16, and 32, respectively. Similarly, in case of code change in table II, 6, 10, 18, and 38 users' simultaneous transmission can be accepted when available number of codes is 2, 4, 8, and 16, respectively.

2. Performance Matrix

For the evaluation of the proposed algorithm we have considered the average access delay and throughput parameters as performance matrices. Average access delay and the throughput are the two fundamental platform under which most of the system’s performance is evaluated.

a. Average Medium Access Delay

Medium access delay is one of the key elements to evaluate the performance of a network. Medium access delay can be defined as the moment between the SS become ready to send the request to the moment when it successfully send. Let Q_i, $(i = 0, 1, 2, ..., M$), be the probability that SS starts its ranging attempt in state ◢, then

$$\sum_{i=0}^{M} Q_i = 1. \tag{3-16}$$

If T_r be the probability that a ranging attempt will succeed exactly on n^{th} try, then

$$T_n = \sum Q_i . \Pr \text{ \{success on n-th try | ranging attempt started in state ◢\}}$$

$$= \sum Q_i (1 - P_c) P_c^{\,n-1} = (1 - P_c) P_c^{\,n-1}. \tag{3-17}$$

If N_t is the random variable representing the number of retransmission until success, the average number of retransmission per request until success, n_t, is given by

$$n_t = E[N_t] = \frac{P_c}{1 - P_c}. \tag{3-18}$$

Therefore, on average it requires $n_t + 1 = \frac{1}{1-P_c}$ transmission per request. If the request is retransmitted N_t times, then on average the request will be delayed by D frames. Thus

$$D = \frac{n_t + 1}{P_t} - 1. \tag{3-19}$$

b. Throughput

Throughput is another key element to evaluate the performance of a network. In communication networks, throughput can be defined as the rate of successful transmission of the data packets over the channel. To calculate the throughput in our model we assume that a successful transmission of the ranging request is possible only when there is only one transmitting SS in an arbitrary time frame. Therefore, the probability of successful transmission in a frame can be represented as

$$P_{succ} = \binom{N}{1} P_t \left(1 - P_t\right)^{N-1} = N P_t \left(1 - P_t\right)^{N-1}. \qquad (3\text{-}20)$$

Where $\binom{N}{1}$ is the way of choosing one out of N. Let us normalize a frame time as a unit time then the average number of frames that are transmitted successfully in any given unit time duration is P_{succ}. Thus the throughput can be simply taken as P_{succ}.

D. Proposition 1: Combined Binary Exponential and Linear Backoff (CBELB) Algorithm

1. Introduction

In this section, a contention resolution backoff algorithm termed Combined Binary Exponential and Linear Backoff (CBELB) algorithm is discussed and proposed for performance enhancement in OFDMA based BWA network. In CBELB algorithm, for first four initial collisions, the colliding SS increases its contention window size exponentially with the factor of 2, whereas in case of further successive collision, the SS increases the contention window size linearly until the maximum number of retransmission is reached. In case of successful transmission or collision after maximum retransmission, SS starts from the beginning as the newly arrived SS. Implementation of CBELB algorithm in the OFDMA based BWA network reduces the average access delay for the successful ranging request transmission in comparison to BEB when there is moderate traffic in the network.

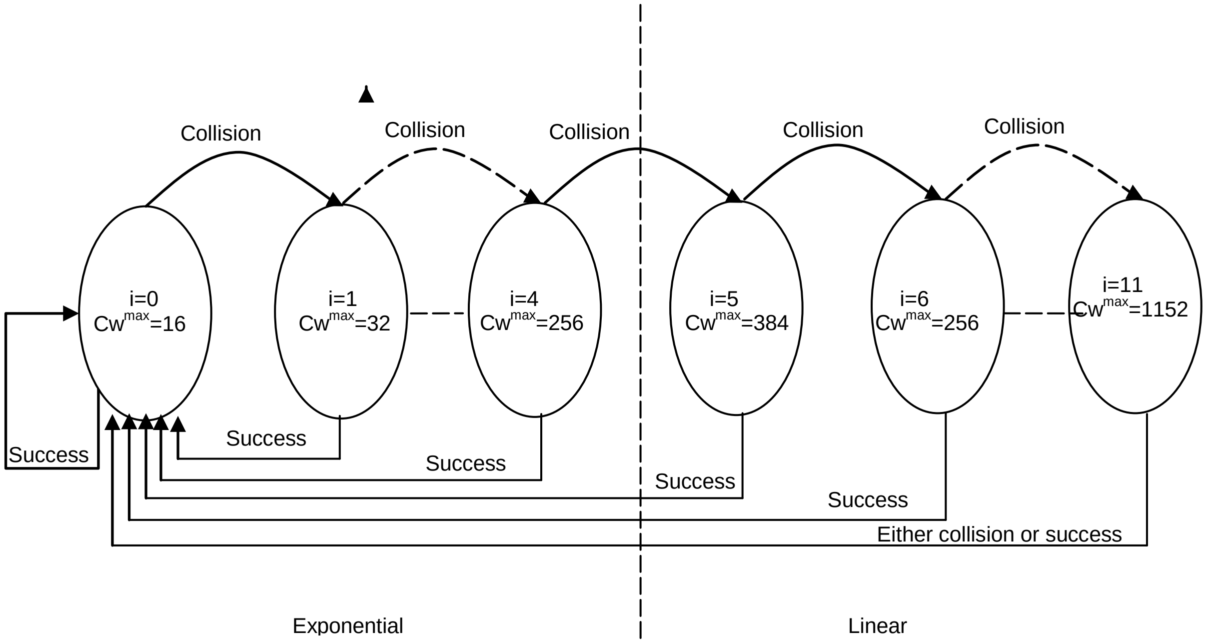

Figure 3- 8: State transitions of the SS for the CBELB algorithm with maximum number of contention window for each state.

In CBELB algorithm, collision probability of ranging request is independent of the number of retry times but depends in number of contention ranging request. The contention window size goes on increasing linearly after the fourth retry times so that average waiting time reduces than that of BEB. All the procedure is similar like that of TBEB till the fourth time collision but after the fourth time collision the SS enters into linear backoff. The target of this algorithm is to reduce the medium access delay for successful transmission when there is moderate type of load in the network. CBELB algorithm can be expressed as follows:

Let i be the number of state, $0 \le i \le M$. During initial network entry SS enters into state $i = 0$. SS can transit the states up to state M by increasing the value of i, by 1, in every successive collision. In our case $M = 12$. In any state i, SS randomly selects a backoff value from the range of $Cw^{\min}$ and $Cw_i^{\max}$, where $Cw_i^{\max}$ represents the maximum contention window value for state i. Once the backoff value is selected, SS waits till that value deferred to 0 before its next transmission. On the very next opportunity it transmits the request. Once there is collision, i is increased by 1. In case of successful transmission, SS starts the next procedure again from the initial state, $i = 0$.

Assuming $Cw^{\min} = 2^4 - 1$, the procedure of CBELB is defined as below

1. On entry:

   $Cw_0 = [0 - (2^4 - 1)]$, and $k_0 = rand\,\mathrm{int}[0 - (2^4 - 1)]$, where $rand\,\mathrm{int}$ is a function to select random integer value, Cw_0 is contention window size on the first entry, and k_0 is backoff value selected randomly in the state $i = 0$. If Cw_i is a contention window for the state i, and k_i is the randomly selected backoff value, then $k_i = rand\,\mathrm{int}[Cw_i]$.

2. On collision:

   $$\begin{aligned} Cw_i &= [0 - 2^{i+4} - 1], \quad 1 \le i \le 4, \\ &= [0 - Cw_{i-1} + 128)], \quad 5 \le i \le M. \end{aligned}$$

3. After state M:

   $Cw_{M+1} = Cw_0.$

4. After success

   $Cw_s = Cw_0.$

2. Performance Evaluation

For the performance evaluation of the CBELB algorithm, we compare its performance with BEB algorithm in terms of medium access delay. Average access delay is one of the widely used performance evaluation matrices. To demonstrate the efficiency of CBELB algorithm, we consider 1-D markov chain model with number of states 13, as shown in Figure 3-9, and the mathematical relations as discussed in section III-B.

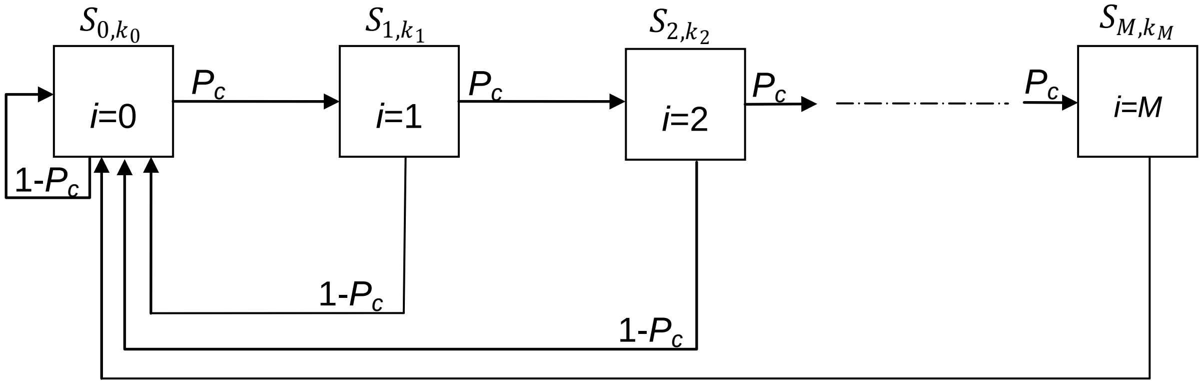

Figure 3- 9: State transistion diagram for markov chaina analysis of CBELB algorithm

But instead of random number generator we analyze the model assuming that the stay of any SS in any state is the average of the maximum waiting time of that particular state. i.e,

$$\overline{k_i} = E[k_i + 1] = \frac{Cw_i^{\max}}{2}. \tag{3-21}$$

Figure 3-10 is the plot of eq. (3-13) and (3-15). The red and blue lines, marked '+' and '*', are plot of eq. (3-13) for CBELB and BEB, respectively. The black lines, rest of the lines, are plot of eq. (3-15) for N=20, 50,100, and 200 with number of CDMA code, C=4.

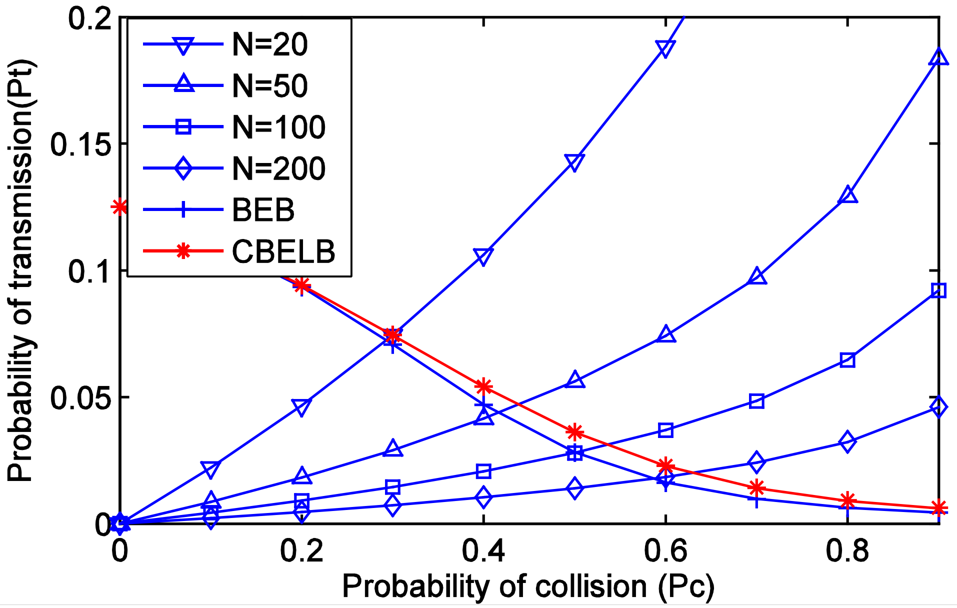

Figure 3- 10: Plot of probability of collision and probability of transmission for eq. (3-13) and (3-15) for analysis of CBELB algorithm.

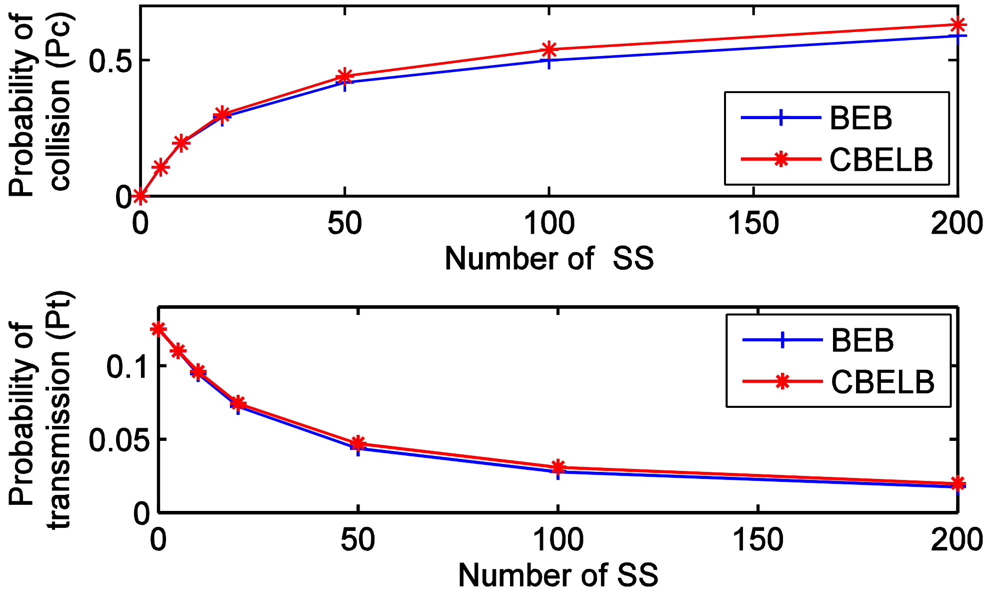

Figure 3- 11 : Plot of the probability of collision and probability of transmission from fixed point analysis in Figure 3-10.

Figure 3-11 is the plot of P_c and P_t, obtained from the point of intersections of Figure 3-10, with respect to number of *SS*. From upper window of Figure 3-11, increase in number of *SS* increases the probability of collision. As the number of *SS* increases, probability of selecting the same code increases, which increase the probability of collision. From lower window of Figure 3-11, increase in number of *SS* decreases the probability of transmission, because increase of probability of collision causes higher waiting time. Hence increase in average waiting time decrease the probability of transmission.

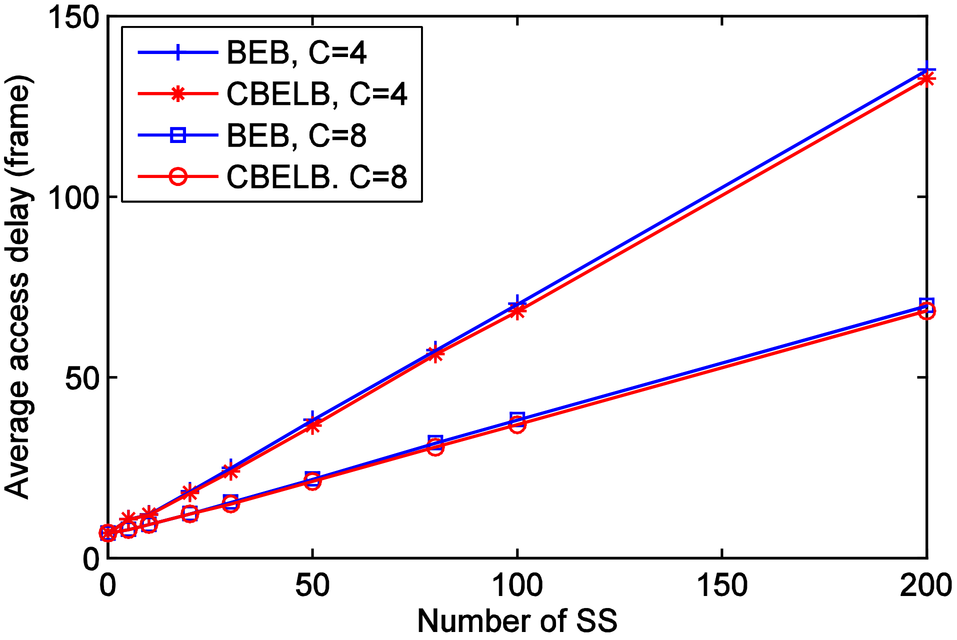

Figure 3- 12: Plot of average medium access delay with respect to number of SS for available CDMA code C=4 and C=8.

From the analysis of the average access delay, eq. (3-20) and Figure 3-12, the average access delay goes on increasing linearly with increase in number of *SS* [12]. If we consider a point with *SS*=100 and *C*=4, the average access delay reduce by , $\frac{71-68}{71}*100 = 4.23\%.$

E. Proposition 2: Utility Based Backoff (UBB) Algorithm

1. Introduction

As a part of an efficient MAC protocol, CRA is used to minimize the probability of collision between the active SSs by dynamically adjusting the backoff value. In general, collision probability is independent of the number of retry times but depends on number of SSs. An efficient CRA is that which grants transmission opportunity to only one active SS suspending other contending SSs and keeping them in backoff state without delay, loss of throughput, and unfairness. In BEB scheme, as mentioned earlier, the Cw size is set to be initial minimum value upon successful transmission whereas it increases by 2-exponential on collision. Thus in BEB, often the SSs with good channel characteristics receive more favor. As the backoff value in BEB is uniform random distribution, a SS with poor channel condition often suffers from large delay and unfairness when the SS fails to transmit his request resulting to increase the contention window size exponentially and competing for the same channel with the other SSs having small backoff value.

To insert the more dynamic property in contention window selection than that of legacy algorithm, we propose here a new backoff algorithm, so called UBB. The key idea of UBB is to give smaller backoff window to the SS according to the given utility (satisfaction), if it has been waiting for longer duration in the previous trail. Utility function is introduced based on SS's deferred backoff value on the previous state. It is expected that all the SS goes towards the average waiting time of the system by the expansion or contraction of Cw in every attempt. In UBB algorithm, the term utility stands as a satisfaction of one SS upon its own selection of the backoff value in the previous transmission attempt. The word utility is very common in the economics. In economics, utility is a measure of the relative satisfaction from or desirability of consumption of goods [18]. It has been brought into networking research in recent years where it represents the “level of satisfaction” of a user or the performance of an application [19-21].

In this algorithm, instead of exponential increment, the contention window increment is the function of the utility (or satisfaction) of the SS upon its deferred backoff value on the previous state. Higher the backoff value in the previous state, lower will be the range of contention window size and vice versa. The target of this algorithm is to reduce the medium access delay for successful transmission without loss of channel throughput. We have quantized the utility (from 0 to 1) into five classes, $\{U_j\}$ when $1 \le j \le 5$, according to the spending time in the previous state on each SS and assigned the level of satisfaction to each class. According to the level of satisfaction the scaling factors $\{\alpha_{U_j}\}$, $0 \le \alpha_{U_j} \le 1$, are assigned to each utility class in order to scale the range of contention window. An example is shown in Table. 1.

Let i be the number of state, $0 \le i \le M$. During initial network entry SS enters into state $i = 0$. SS can transit the states up to state M by increasing the value of i, by 1, in every successive collision. In our case $M = 12$. In any state i, SS randomly selects a backoff value from the range of $Cw^{\min}$ and $Cw_i^{\max}$, where $Cw_i^{\max}$ represents the maximum contention window value for state i. Once the backoff value is selected, SS waits till that value deferred to 0 before its next transmission. On the very next opportunity it transmits the request. Once there is collision, i is increased by 1. In case of successful transmission, SS starts the next procedure again from the initial state, $i = 0$.

Assuming $Cw^{\min} = 2^4 - 1$, the procedure of UBB is summarized as below

1. On entry:

   $Cw_0 = [0-(2^4-1)]$, and $k_0 = rand\,\mathrm{int}[0-(2^4-1)]$, where $rand\,\mathrm{int}$ is a function to select random integer value, Cw_0 is contention window size on the first entry, and k_0 is backoff value selected randomly in the state $i = 0$. If Cw_i is a contention window for the state i, and k_i is the randomly selected backoff value, then $k_i = rand\,\text{int}[Cw_i]$.

2. On collision:

   If $k_i \in U_j, k_{i+1} = rand\,\text{int}[0-(2^{i+4}+\alpha_{U_j}2^{i+4}-1)]$ $Cw_i = [0-(2^{i+4}-1)]$, where $1 \le j \le 5$.
3. After state M:

   $Cw_{M+1} = Cw_0$
4. After success

   $Cw_s = Cw_0$

2. Performance Evaluation

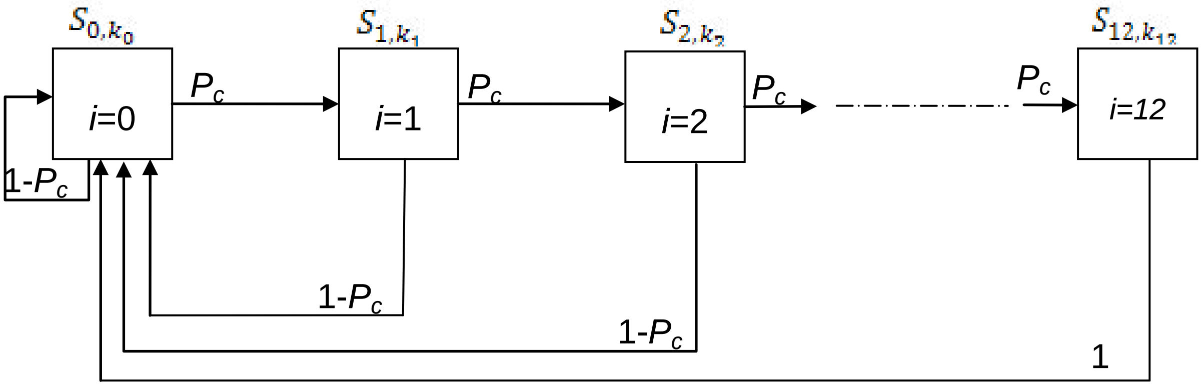

Figure 3- 13: State transition diagram for markov chain analysis of UBB Algorithm.

To demonstrate the efficiency of UBB algorithm, we compare its performance with that of BEB algorithm in terms of average medium access delay and normalized throughput. Considering the 1-D markov chain model with number of state 13, as shown in Figure 3-13, and the mathematical relations as discussed in section III-B, we simulate our model using MATLAB as a simulation tool with the utility function as presented in Table 3-3. Simulation is run for 100 times, and average values are taken. In this simulation we fixed M at 12.

Table 3- 3: Utility (satisfaction) function of proposed UBB algorithm.

Utility Class			Scaling Factor	
U_j	Selected backoff value in state ◢		α_{U_j}	Value
U_1	$k_i \le 2^{i+4} * 0.125$		α_{U_1}	1
U_2	$2^{i+4} * 0.125 < k_i \le 2^{i+4} * 0.375$		α_{U_2}	0.75
U_3	$2^{i+4} * 0.375 < k_i \le 2^{i+4} * 0.625$		α_{U_3}	0.5
U_4	$2^{i+4} * 0.625 < k_i \le 2^{i+4} * 0.875$		α_{U_4}	0.25
U_5	$k_i > 2^{i+4} * 0.875$		α_{U_5}	0

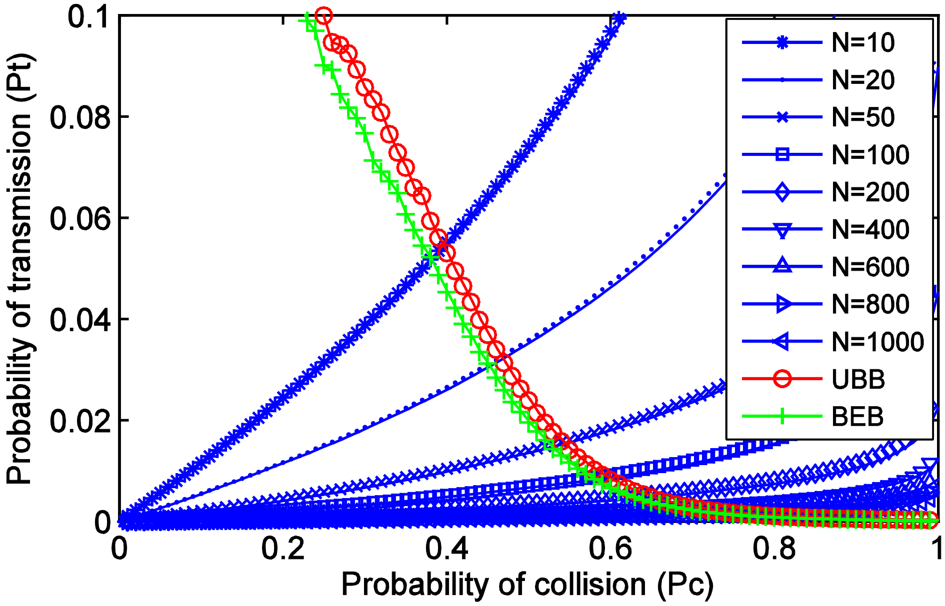

Figure 3- 14: Plot of probability of collision and probability of transmission for eq. (3-13) and (3-15) for analysis of UBB algorithm.

Figure 3-14 depicts the curves of probability of collision and probability of transmission according to eq. (3-13) and (3-15). In the figure, `+' and `o' lines represent the probability of transmission of a SS in an arbitrary frame with UBB and BEB algorithm according to the given probability of collision, respectively.

Rest of the lines represents the probability of transmission in a frame for the given probability of collision while there are 10, 20, 50, 100, 200, 400, 600, 800, and 1000 SSs in the network with available CDMA code $C = 1$.

If all SSs in steady state has the same backoff parameters, they will all see the same average collision probability, P_c, and hence they will have same transmission probability, P_t. Thus from fixed point analysis, i.e. from intersection points in Figure 3-14, we can get P_c and P_t of a SS during an arbitrary frame time.

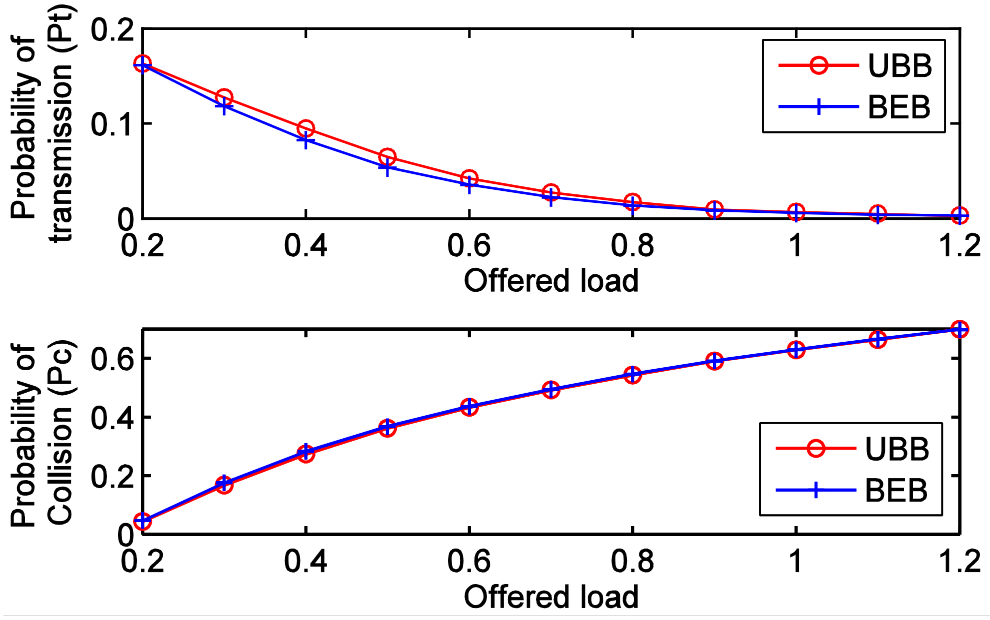

Figure 3- 15: Plot of probability of collision and probability of transmission with respect to offered load from fixed point analysis in Figure 3-14.

Once we get the probability of transmission we can calculate the offered load at a particular frame offered by the respective number of SSs [22]. Figure 3-15 shows the plots of P_c and P_t, obtained from the intersection points in Figure 3-14, with respect to offered load. From the lower window of Figure 3-15, the higher offered load increases the probability of collision. From upper window of Figure 3-15, the higher the offered load is the lower the probability of transmission. It is because high probability of collision causes the higher backoff value which leads to the lower probability of transmission.

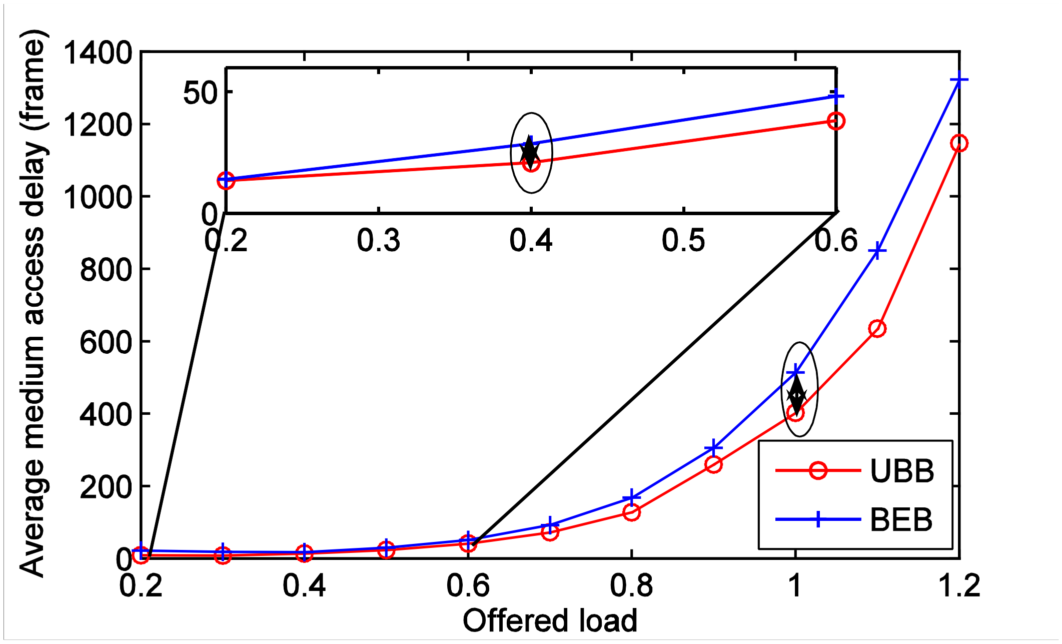

Figure 3- 16: Plot of the average medium access delay with respect to offered load.

Figure 3-16 depicts the average access delay with respect to the offered load. The projected part shows the delay difference while the offered load is low (it is not clearly distinguishable in original lines because of high scale). Average access delay goes up with increase to the offered load. As the number of SSs increases the probability of collision, there will be higher waiting time because of backoff. From Figure 3-16, average waiting time is always less for the UBB in comparison with BEB. Note that delay is reduced by 11% and 22 % when the offered load is 0.4 and 1, respectively.

The normalized throughput with respect to the offered load is presented in Figure 3-17. Throughput increases until the offered load is 1, then it decreases. Higher probability of transmission leads the probability of remaining idle frame lower which obviously increases the throughput. On the other hand, when the offered load exceeds the maximum capacity, throughput decreases because of high probability of collision. From Figure 3-17 the normalized throughput is higher in

UBB for lower offered load and it is never less than BEB in higher offered load. Note that there is 6% throughput gain when offered load is 0.3 and is slightly higher or similar in the case of the offered load greater than 0.6.

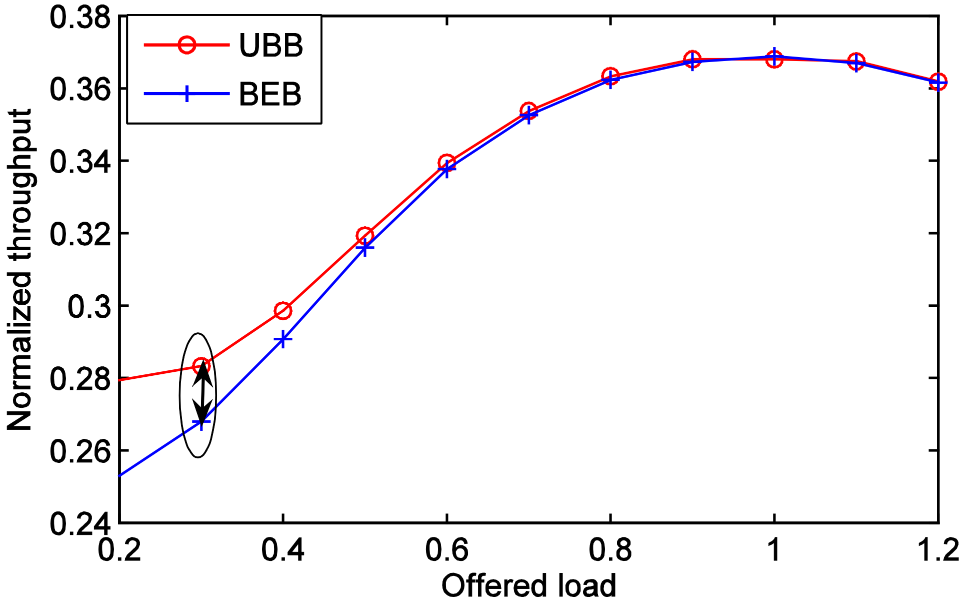

Figure 3- 17: Plot of the normalized throughput with respect to offered load.

From the simulation results, comparing with BEB, the proposed algorithm gives higher throughput with low delay when there is low traffic in the network. Furthermore, it gives low delay without any throughput loss when there is high traffic. We conclude that the proposed UBB is well adaptable not only for the delay tolerant and throughput sensitive network in the case when offered load is low but also for the delay sensitive network in all range of the offered load. We conclude that, as a whole, the proposed algorithm outperforms the well known BEB algorithm. In addition, UBB algorithm can also outperforms our proposed CBELB algorithm in all domains like throughput, delay and fairness.

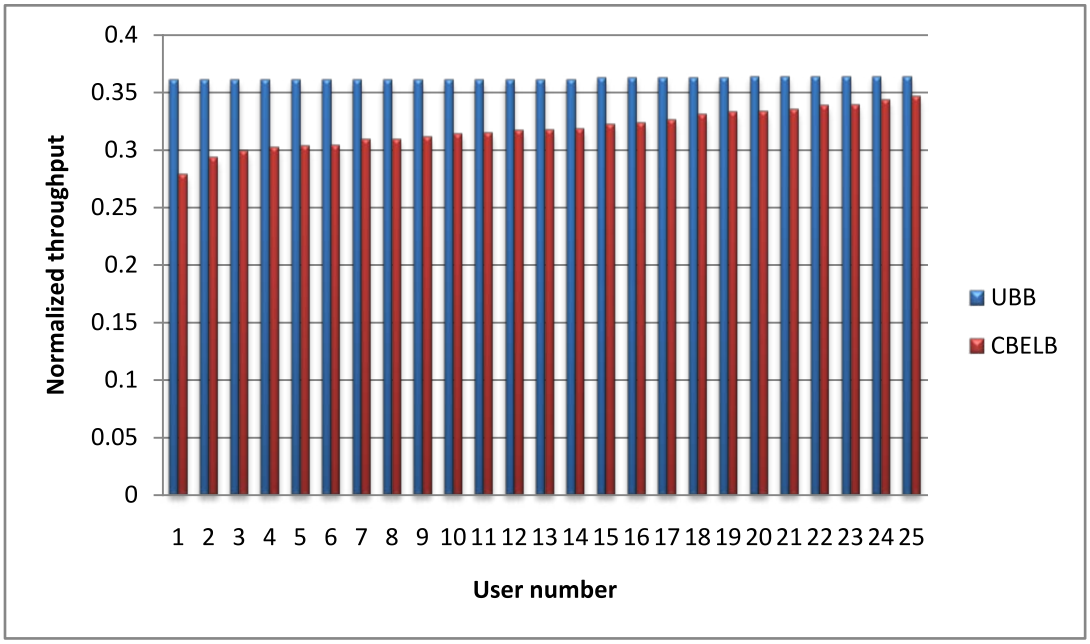

Figure 3- 18: Superior performance with fairness of UBB algorithm in terms of throughput when comparing with CBELB algorithm.

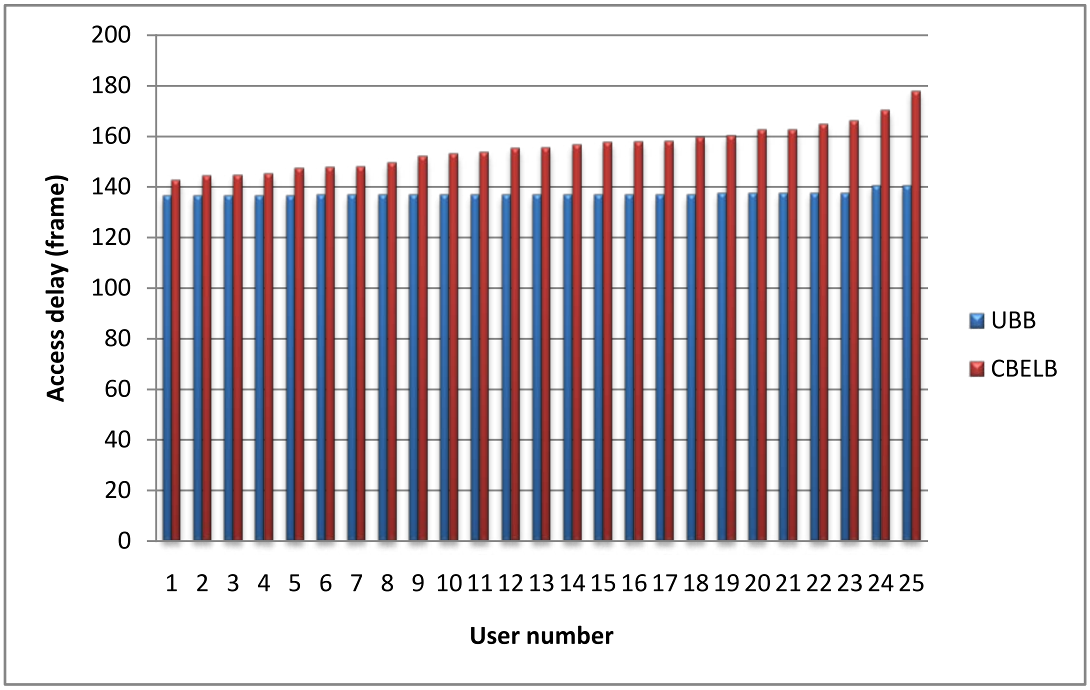

Figure 3- 19: Superior performance with fairness of UBB algorithm in terms of delay when comparing with CBELB algorithm.

Figure 3-18 and Figure 3-19 shows the UBB algorithm’s superior performance with fairness in comparison with CBELB in terms of throughput and delay, respectively. The figures depict that for the user 1 to user 25 on the network with 50 SSs in saturated condition, both the delay and throughput are fairly distributed for UBB, however, CBELB fails to maintain fairness.

IV. Conclusion and Future Work

The contributions we made in the CRA in this carried research were presented in chapter three. We develop the model for the mathematical analysis of the ranging code collision probability and transmission probability by any SSs while they are in saturated networks. Then we proposed two new CRAs schemes, CBELB and UBB, to overcome the limitations of the legacy CRA, BEB. We analyzed the efficiency of the proposed algorithms and presented the analytical and simulation results to revel the better performance they owned in compare to legacy one.

A ranging code collision probability while using BEB algorithm for any OFDMA based BWA network like IEEE 802.16 is analyzed mathematically. Simulation results depict the collision probability dependency in three domains; CRA, available number of ranging codes, and number of users. The network's requirement can be satisfied by adjusting any of the three parameters.

In first proposition, we discussed and proposed the new backoff algorithm CBELB. We analyzed the proposed algorithm mathematically and observed the performance in terms of medium access delay. Medium access delay increased linearly with increase in number of SS in both BEB and CBELB algorithm but the increase in delay is comparatively less in CBELB algorithm. Therefore, CBELB is a new backoff algorithm, which is a combination of traditional binary exponential backoff algorithm with linear backoff algorithm that reduces a medium access delay in the system.

In second proposition, a new CRA named as UBB was proposed to enhance the performance of legacy algorithms. We verified our proposed UBB with adapting it to the OFDMA based BWA network for the ranging procedure. The key idea of UBB is to give less backoff window to the *SS* according to the given utility, if it has been waiting for longer duration in the previous trail. The simulation results revel that the proposed algorithm outperforms the legacy algorithm in terms of throughput and delay.

Obviously, the three domains; CRA, number of users, and available resources determine the collision probability in the network. However, increasing the resources increase the capital and simultaneously leaves the possibility of the resources being wastage during low traffic. Similarly, decreasing the number of users means decreasing the revenue. Thus using the efficient CRA to distribute the available resources in an effective way is the best solution for any network. Therefore, we study the CRA schemes and proposed the new schemes. Though we analyzed our algorithms for the OFDMA based BWA network, they can be implemented in any other networks which employ backoff algorithm for CRA in shared channel access.

Bibliography

[1] Nah-Oak Song, Byung-Jae Kwak, Jabin Song, Miller M.E, “Enhancement of IEEE 802.11 Distributed Coordination Function with Exponential Increase Exponential Decrease Backoff Algorighm ,’’ in Proc. VTC 2003, vol. 4, pp. 2775-2778, 2003.

[2] V. Bharghavan, A Demers, S. Shenker, and L. Zhang, “Macawa: A Media Access Protocol for Wireless Lans,” in Proc. ACM SIGCOMM’94, 1994.

[3] P. Chatzimisios, A. C. Boucouvalas, V. Vitsad, A. Vafiadis, A. Oikonomidis, and P. Huang, “A Simple and Effective Backoff Scheme for the IEEE 802.11 MAC Protocol,’’ in Proc. CITSA, 2005.

[4] Saher S. Manaseer, Mohamed Ould-Khaoua, “Logarithmic Backoff Algorithm for MAC Protocol in MANETS,” in Proc. 4th International Multiconference on Computer Science and Information Technology, pp. 481-487.

[5] Byung-Jae Kwak, Nah-Oak Song, and Dong Seung Kwon, “Enhancement of IEEE 802.16 WirelessMAN Ranging Performance with EIED Backoff Algorithm,’’ in Proc. VTC-2007 fall, pp. 1902-1906, 2007.

[6] J. Deng, P.K. Varshney, and Z. J. Hass, “A New Backoff Algorithm for the IEEE 802.11 Distributed Coordination Function,’’ in Proc. CNDS’04, 2004.

[7] Wikimedia Foundation, “Exponential Backoff,” [Online document], 3 November 2008, Available: http://en.wikipedia.org/wiki/Exponential_backoff

[8] Kelly, F.P, “Stochastic Models of Computer Communication System,” J. Roy. Statist. Soc. B 47, pp. 379-395, 1985.

[9] Kelly, F.P, MacPhee, I.M, “The Number of Packets Transmitted by Collision Detect Random Acess Scheme,” Annals of Prob. 15, pp. 1557-1568, 1987.

[10] D. J Aldous, “Ultimate Instability of Exponential Backoff Protocol for Acknowledgement based Transmission Control Random Access Communication Channels,” IEEE Trans. Information Theory, vol. 33, no. 2, 1987.

[11] J. Goodman, A.G. Greenberg, N. Madras, and P. March, “Stability of Binary Exponential Backoff,” Journal of the ACM, vol. 35, no. 3, 1988.

[12] Byung-Jae Kwak, Nah-Oak Song, and Leonard E. Miller, “Analysis of the Stability and Performance of Exponential Backoff” in Proc. WCNC, vol. 3, pp. 1754-1759, 2003.

[13] R. Prasad, “OFDM for Wireless Communication Systems,’’ Artech house, USA, 2004.

[14] Specification for 2.3 GHz Band Portable Internet Service-Physical & Medium Access Control Layer-, TTA Std., 2005.

[15] IEEE 802 part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, IEEE Std., 2005.

[16] Andrey Lukayanenko, “On the Optimality and the Stability of Backoff Protocols,” in Next Generation Teletraffic and Wired/Wireless Advance Networking, Springer Berlin/Heidelberg, vol. 471/2007, pp. 393-408, 2007.

[17] Kumar A, Altman E, Miorandi D, and Goyal M, “New Insights from a Fixed-Point Analysis of Single Cell IEEE 802.11 WLANs,” in Proc. INFOCOM 2005, vol. 3, pp. 1550-1561, 2005.

[18] Wikimedia Foundation, “Utility,” [Online document], 12 October 2008, Available: http://en.wikipedia.org/wiki/Utility

[19] Ning Lu and John Bigham, “On Utility Fair Bandwidth Adaptation for Multi-Class Traffic QoS Provisioning in Wireless Networks,” Computer Networks, vol. 51, pp. 2554-2564, 2007.

[20] Guocong Song and Ye (Geoffrey) Li, “Utility-Based Resource Allocation and Scheduling in OFDM-Based Wireless Broadband Networks,” IEEE Communication Magazine, vol. 43, pp. 127-134, 2005.

[21] Mehri Mehrjoo, Mehrdad Dianati, Xuemin (Sherman) Shen, and Kshirasagar Naik, “Opportunistic Fair Scheduling for the Downlink of IEEE 802.16 Wireless Metropolitan Area Networks,” in Proc. ACM International Confrerence 2006, vol. 191, article no 52, 2006.

[22] Abi-Nassif F, Whay Chiou Lee, and Stavrakakis I, “Offered Load Estimation in Multimedia Cable Networks,” in Proc. ICC’99, vol. 1, pp. 140-146, 1999.

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저작물 이용 허락서

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논문제목	한글 : 광대역 무선 통신에서 성능 향상을 위한 충돌 해소 알고리즘에 대한 연구 영어 : A Study on Contention Resolution Algorithms for Performance Enhancement in BWA				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 -조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의( ) 반대( )

2008년 12월 10일

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