Performance Enhancement of BWR Mechanism in 802.16 WiMAX Networks by Cyclic Prefix Insertion and Circularity

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***Abstract*— In the IEEE 802.16 standard, Bandwidth Request (BWR) is the mechanism by which the SS communicates its need for uplink bandwidth allocation to the BS. In this, we evaluate the performance of this scheme based on the metrics of delay and throughput. Then, we enhance its MAC layer performance by incorporating circularity. Circularity is a paradigm that allows the identification of specific groups of packets or events. Using this, we introduce selective dropping of BWR packets. This new paradigm reduces the collisions among request packets and thereby, improves this mechanisms. Further, to improve performance we enhance the modulation techniques in Physical Layer by introducing Cyclic Prefix. The evaluation and enhancements are performed through extensive simulation studies.**

Keywords—BWR, Circularity, Cyclic Prefix Insertion, OFDMA

I. Introduction

Worldwide Interoperability for Microwave Access (WiMAX) is a consortium founded to facilitate the interoperability and foster the commercialization of products based on the IEEE 802.16 standard. The current IEEE 802.16-2004 standard with the extensions for mobility support revised in the IEEE 802.16e-2005 standard is the basis for two classes of WiMAX certified products. The Orthogonal Frequency Division Multiplexing (OFDM) part of IEEE 802.16-2004 is known as Fixed WiMAX and the Orthogonal Frequency Division Multiple Access (OFDMA) part of IEEE 802.16e-2005 is known as Mobile WiMAX **[1]**.

WiMAX will transform telecommunications, as it is known throughout the world today. It eliminates the resource scarcity that has sustained incumbent service providers for the last century. As this technology enables a lower barrier to entry, it will allow market based competition in all of the major telecommunication services: voice (mobile and static), video, and data.

Originally envisioned for Fixed Broadband Wireless Access (FBWA) networks and as a wireless competitor for wire-line DSL and cable modem access in particular in rural and low-infrastructure areas, the most recent stage of the IEEE 802.16 standard also provides mobility support mainly intended for nomadic users or users with little mobility.

Since the beginning of the telephone, service providers have staved off competition by relying on the steep capital investment necessary to deploy a telephone network. The cost of deploying copper wires, building switches, and connecting the switches created an insurmountable barrier to entry for other competitors. In most of the world, the high cost of this infrastructure limited telephone service to the wealthy and the fledgling middle class**.**

A. Overview of 802.16 PHY

The IEEE 802.16 standard specifies four physical layers viz. Single Carrier (SC) and Single Carrier-a (SCa) for single carrier transmission in line-of-sight and non-line-of sight environments, OFDM and OFDMA for multi-carrier transmission in non-line-of-sight environments. A common Medium Access Control (MAC) sublayer is defined for all physical layers with only small adaptations to the different physical layers. The standard specifies two modes of operation, point-to-multi-point (P2MP) and mesh mode. In this paper we focus on point-to-multipoint communication and the SC, SCa and OFDM physical layers. In P2MP mode of operation a base station can communicate with subscriber stations and/or base stations **[2]**.

B. Overview of 802.16 MAC

The MAC sublayer is present within the Data Link layer of Open Systems Interconnection (OSI) model. MAC sublayer serves as a link between lower hardware oriented PHY layer and other upper software driven layers. IEEE 802.16 MAC sublayer is further divided into three parts as Service specific Convergent Sublayer (CS), Common Part Sublayer (CPS), and Privacy Sublayer (PS). The MAC layer functions are Admission Control, Link Initialization, Fragmentation, Transmission Scheduling**,** Retransmission and support for integrated Voice/Data connections.

Data units between the BS and SSs are transmitted by using fixed-length frames. It comprises of a downlink and an uplink subframe. The downlink subframe is used to transfer data from the BS to SSs and the uplink for data transfer in opposite direction. The border between two subframes is adaptive according to the data amount in downlink and uplink. Every frame contains an integer number of OFDM symbols carrying MAC datagrams. These OFDM symbols encompass MAC resources available for data transmissions. Sharing of MAC resources between SSs is centralized in the BS. Downlink map (DL-MAP) and uplink map (UL-MAP) signaling messages are used to inform SSs about bandwidth allocations in downlink and uplink. A preamble for synchronization, at the beginning of the downlink subframe is transmitted, followed by the broadcast MAC signaling messages **[3].**

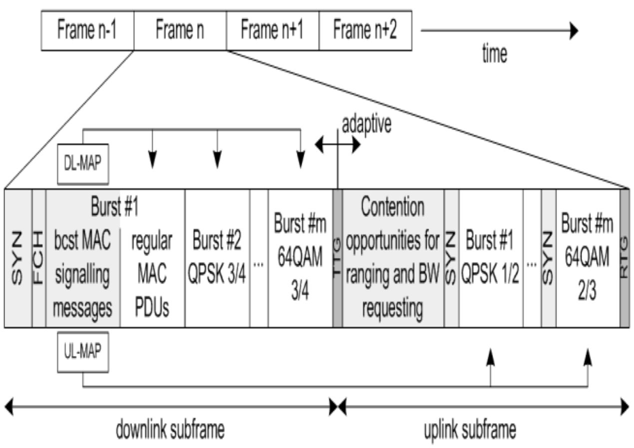

Fig.1. Frame Structure of IEEE 802.16

The burst may start from a preamble that can be of three types, first is Long that is used in the cases when there is no exact information on the timing of the burst's arrival e.g. when SS is transmitting first time trying to synchronize with BS. The second type is Short that used in the cases when there is exact information on the timing of the burst's arrival, and the third is Mid-amble that is inserted for synchronization purposes between consequent bursts. Thereafter the bursts consisting of user data are transferred to particular SSs using different modulation types and coding rates. The Transmit/Receive (Tx/Rx) transition gaps are inserted between the subframes to allow stations to switch between reception and transmission operation modes. The uplink subframe begins with contention intervals scheduled for initial ranging and bandwidth request opportunities. Initial ranging is used during network entry by new SSs to adjust their time and power parameters. Within a bandwidth request interval a SS may indicate its need of resources to transmit data to the BS.

II. BWR MECHANISM

Bandwidth Request (BWR) is the mechanism by which the SS communicates its need for uplink bandwidth allocation to the BS. A single WiMAX cell consists of a base station (BS) and multiple subscriber stations (SSs). The BS schedules the traffic flow in the WiMAX i.e., SSs do not communicate directly. The communication between BS and SS are bidirectional i.e., a downlink channel (from BS to SS) and an uplink channel (from SS to BS). The downlink channel is in broadcast mode. The uplink channel is shared by various SS's through time division multiple access (TDMA). The subframe consists of a number of time slots. The duration of subframe, slots and the number are determined by the BS scheduler. The downlink subframe contains uplink map (UL map) and downlink map (DL map). The DL map contains information about the duration of sub frames and which time slot belongs to a particular SS as the downlink channel. The UL map consists of information element (IE) which includes transmission opportunities.

BWR request packets are of multiple types and can be stand-alone or piggybacked BWR message. The requests must be made in terms of the number of bytes of data needed to be sent and not in terms of the channel capacity, because the uplink burst profile can change dynamically. There are two methods for sending bandwidth request namely, Contention Free method and Contention Based method. In contention free bandwidth request method, the SS will receive its bandwidth automatically from BS. In contention based bandwidth request method, more than one subscriber can send their request frames to same base station at same time, for bandwidth. Hence there will be chances of collision, which is resolved by Truncated Binary Exponential Backoff Algorithm. BE and nrtPS services are two cases of contention based request method.

In the uplink subframe of the TDD frame structure of 802.16, there are a number of Contention Slots (CSs) present for the purposes of BWR. In contention based bandwidth request mechanism, an SS attempts to send its BWR packet in one of these contention slots in the uplink subframe to the BS. If a BWR packet is successfully received by the BS and bandwidth is available, then the bandwidth is reserved for the SS and it can transmit its data without contention in the next frame. In case multiple subscriber stations send their request messages to the same BS at the same time, there will be a collision. So, here the contention is resolved by using the truncated binary exponential backoff procedure. The minimum and maximum backoff windows are decided by the BS. Also, the number of bandwidth request retries is 16. The backoff windows are always expressed in terms of powers of two. This algorithm solves retransmission strategy after a collision. It keeps track of the number of collisions**.**

A Subscriber Station can transmit its bandwidth request using bandwidth request contention slots known as BWR contention slots. Subscriber stations can access the channel using Random Access Channel (RACH) method. A subscriber station that wants to transmit data first enters into the contention resolution algorithm. In this scheme we consider different number of contention slots for each frame and each subscriber station has 16 transmission opportunities at maximum. The Initial Backoff window size is 0-7 and the final maximum backoff window size is 0-63. While accessing the channel randomly this way, there will be collisions among these request packets. Suppose the backoff window at a certain time for an SS is 0 to 15 (0 to 2^4-1) and the random number picked is 8. The SS has to defer a total of 8 BWR Contention Slots before transmitting the BWR packet. This may require the SS to defer BWR Contention Slots over multiple frames. In case a collision is detected, the backoff window is doubled. Now a random number is picked between 0 and 31 and the deferring is continued. This procedure can be repeated for a maximum of 16 times after which the data that was to be sent is discarded and the whole process is restarted from the very beginning.

Base station can allocate bandwidth to subscriber station in three ways: Polling, GPC (Grant per Connection Mode) and GPSS (Grant per Subscribers Station). GPC is a bandwidth allocation method in which bandwidth is allocated to a specific connection within a subscriber station. GPSS is a bandwidth allocation method in which requests for the bandwidth is aggregated for all connections within a subscriber station and is allocated to the subscriber station as that aggregate. The bandwidth requests are always made for a connection.

Polling is the process by which the BS allocates to the SSs bandwidth specifically for the purpose of making bandwidth requests. These allocations may be to individual SSs or to groups of SSs. Polling is done on either an SS or connection basis. Bandwidth is always requested on a CID basis and bandwidth is allocated on either a connection (GPC mode) or SS (GPSS mode) basis, based on the SS capability.

III. EVALUATION AND ENHANCEMENT OF BWR

In IEEE 802.16 networks, the BWR scheme is used by the SSs to communicate its need for uplink Bandwidth to BS. Although the mechanism is completely defined in the IEEE 802.16 standard, the performance of this mechanism is affected by the collisions between the packets sent by different SSs. We propose an enhanced mechanism for BWR, which incorporates the principle of circularity at MAC layer and enhances OFDMA Modulation Techniques at PHY layer.

A. Circularity in MAC Layer

Circularity is a principle that aims to reduce the number of collisions between the request packets in the BWR scheme. It is defined as a number that allows us to identify specific groups of events or packets in the network. The number of packets or events in one such group is equal to the circularity value. In each group, one of the packets or events is said to be circularity-satisfied. Here, we introduce certain control measures in case of circularity-satisfied packets and events. The circularity value is a positive integer. In order to identify the circularity-satisfied packets or events, we keep a count of the number of such packets or events. This count is global in the sense that we do not keep an individual counter for each SS. Whenever the value of this counter is a multiple of the circularity value, the packet or event is said to be circularity satisfied. If the counter is represented by k and the circularity value by c, then the mathematical representation for satisfying circularity is as follows:

$$k \text{ modulo } c = 0$$

In case of the BWR mechanism, the BWR packets are also kept count of. When the packet count of a BWR packet is a multiple of circularity, the packet is said to be circularity-satisfied. Such a BWR packet is discarded [7]. The events that occur in the IR intervals and the BWR contention slots of a particular frame affect the IR intervals and BWR contention slots of not only the next frame but also the frames after that. Consider the BWR contention slots of a particular frame 'U'. If there are many BWR packets sent successfully in a frame, then in the next frame 'U+1' there will be a larger number of uplink data bursts allocated for the data to be sent. This would of course be dependent on the availability of bandwidth in the next frame. A larger amount of data being sent implies fewer resources available on the uplink for contention based processes namely IR and BWR.

In order to explain the effects of the principle of circularity

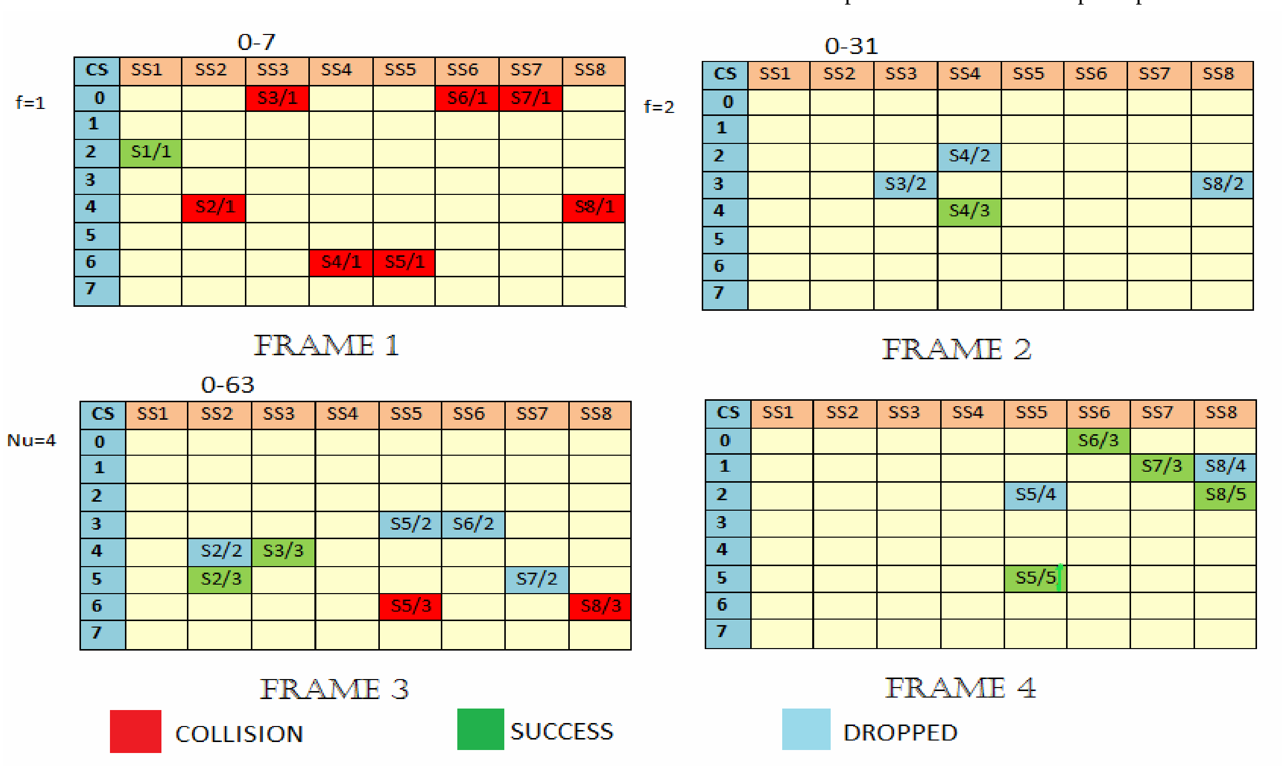

Fig.2. Frame Analysis of BWR Mechanism with Circularity =2

on the bandwidth request mechanism, we carry out a frame analysis that shows the events that occur during the mechanism. Reference **[4]** explains frame analysis of BWR with the principle of circularity as shown in Figure 2.

Consider an example wherein, SS1 tries to transmit its BWR in the first frame i.e. (F1) in the Contention Slot 2. Here, no other SS is transmitting its BWR and SS1 is able to transmit its request message without any collision. Next we consider SS2. SS2 tries to transmit its BWR in the first frame in CS4. But in this CS, SS8 is also sending its BWR. Hence these packets will collide which is denoted by C.

After the collision each SS, doubles its backoff window (if it has not reached a maximum already). Then window. The requisite number of BWR CS is deferred. The second BWR packets of SS2 and SS8 have been dropped, since they are circularity satisfied. This is denoted by D. The backoff window is doubled again. SS2 selects the number 10 and SS8 selects the number 11. With this value selected SS has a successful transmission of its BWR packet. But, SS8 again experiences a collision. The standard backoff procedure is continued in this case. Since the circularity value chosen is k = 2 for simplicity, every alternate request packet is dropped by each SS (Simulation Results indicate k=2 is the ideal value). So by avoiding unnecessary doubling of window we are decreasing the delay involved and thereby improving the performance of the system.

B. *Cyclic Prefix Insertion in PHY Layer*

In telecommunications, the term *cyclic prefix* refers to the prefixing of a symbol with a repetition of the end. Cyclic prefix serves two purposes, though the receiver is configured to discard the cyclic prefix samples. One, as a guard interval, it eliminates the intersymbol interference from the previous symbol. And, second, as a repetition of the end of the symbol, it allows the linear convolution of a frequency-selective multipath channel to be modelled as circular convolution, which in turn may be transformed to the frequency domain

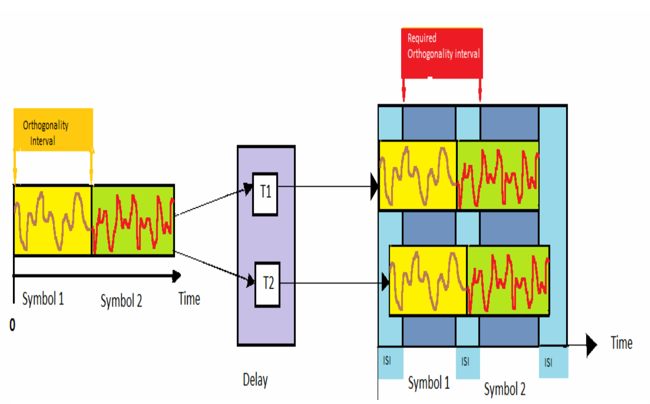

Fig.3. OFDM Transmission Without Cylic Prefix

using a discrete Fourier transform. This method allows for simple frequency-domain processing, such as channel estimation and equalization. In order for the cyclic prefix to be effective (i.e. to serve its aforementioned objectives), the length of the cyclic prefix must be at least equal to the length of the multipath channel. Although the concept of cyclic prefix has been traditionally associated with OFDM systems, the cyclic prefix is now also used in single carrier systems to improve the robustness to multipath.

Cyclic prefix is often used in conjunction with

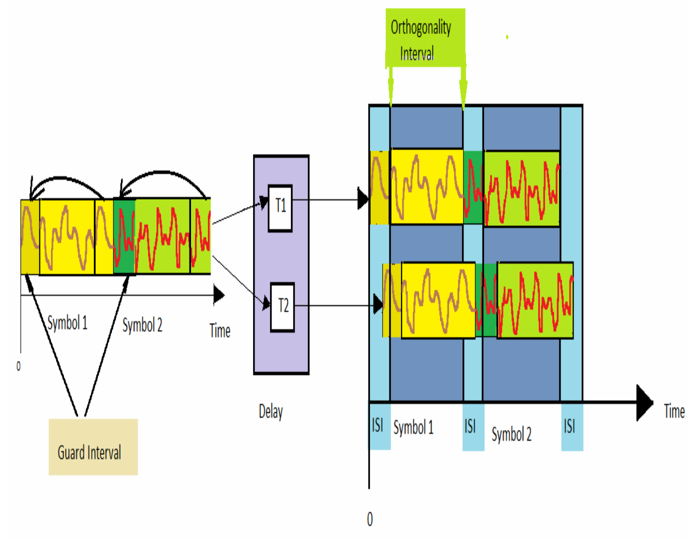

Fig.4. OFDM Transmission With Cylic Prefix

modulation in order to retain sinusoids' properties in multipath channels. It is well known that sinusoidal signals are Eigen functions of linear and time-invariant systems. So, if the channel is assumed to be linear and time-invariant, then a sinusoid of infinite duration would be an Eigen function. But, in practice, this cannot be achieved, as real signals are always time-limited. So, to mimic the infinite behavior, prefixing the end of the symbol to the beginning makes the linear convolution of the channel appear as though it were circular convolution, and thus, preserve this property in the part of the symbol after the cyclic prefix. We mainly use this concept to eliminate ISI and thereby improve efficiency of each modulation technique and thereby improve performance of the whole WiMAX system.

In a real world scenario, a transmitted signal reaches the receiver inside a communication device, not only via the direct path, but also via other parts (e.g., by reflection of the signal on buildings, etc.). This scenario is called multi-path scenario. As the different transmitted signals reach the receiver at different times, they are added up at the receiver site to form a combined signal.

As you can see from the Figure 3, there are two separate regions in the received signal: Only time-shifted version of the signal of the same symbol (symbol1 or symbol2) are added (Dark Blue region) .This effect is called self-symbol interference (SSI). Regions where different symbols (symbol1 and symbol2) are added up together (Light Blue region). This effect is called Intersymbol Interference (ISI) **[5].**Thus, there are basically two disturbing effects that must be reduced.

1. Self-Symbol Interference

OFDM uses orthogonal transmitter frequencies. Orthogonality means that the product of two carriers with different frequencies is zero if samples at the sampling Frequency.

SSI in contrast to other transmission techniques improves the performance of the receiver. Mathematical calculations show that SSI in OFDM systems is not 'destructive' (i.e., transmission is disturbed) but 'constructive' (i.e., the SSI parts add up to form a higher amplitude of the single FFT carriers).

2. Intersymbol Interference

The ISI part of an OFDM transmission cannot be corrected by means of signal processing because the receiver will have no idea about the next symbol being transmitted. This means that the receiver needs an interval with a definite length equal to the useful symbol time to determine the OFDM symbol. This interval is called Orthogonality Interval.

To solve this, a cyclic prefix is introduced. This is achieved by adding the last part of an OFDM symbol to its front part. With this extension, the receiver is able to receive the undisturbed signal for a longer time and demodulate it without any errors as shown by Figure 4. A symbol lies clearly inside the Orthogonality interval in Figure 4. This indicates the elimination of ISI.

IV. Simulation Studies

The Simulation consists of two parts: Simulation of BWR scheme without Circularity Using NS-2 and changing the backend and re-simulating With Circularity and Cyclic Prefix.

A. Simulation Setup

The simulations have been carried out using the Network Simulator 2 (ns-2) which is a discrete event simulator. We have added the WiMAX patch developed by the Advanced Network Technologies Division of the National Institute of Standards and Technologies **[6]**. The simulation script is written in the Tool Command Language (Tcl) **[7], [8]**. The model currently implemented is based on the IEEE standard 802.16-2004.The model currently supports TDD. In this model, the uplink transmission follows only after the downlink occurs in each frame. The DL_MAP and UL_MAP messages determine the bursts of allocation and transmission opportunities for each station. The BS allocates slots that involve contention in the uplink direction. This model resolves contention by using a truncated binary exponential backoff procedure. The BS broadcasts the UCD messages that determine the window sizes. Also the BS decides the number of contention slots allocated in each frame. The WiMAX control agent is used in the Tcl script in order to produce a detailed account of the activities in the network **[9], [10]**.

B. Simulation Scenario

The network configuration used is as follows. A single base station (BS) is considered. A sink node is considered that is attached through a wired link to the BS. The number of subscriber stations is simulated with BS. The performance metrics used are the delay, collision and throughput. The values for these metrics are calculated from the output file generated by the WiMAX control agent.

The key parameters are as shown

Channel Type	Wireless Channel
Radio Propagation Model	TwoRayGround
Network Interface Type	Phy/WirelessPhy/OFDM
MAC Type	802_16
Interface Queue Type	Drop Tail Priority Queue
Link Layer Type	LL
Antenna Model	Omni Antenna
Minimum Packets in Interface Queue	50
Routing Protocol	DSDV
BS Coverage	20 meters
Simulation Time	50 seconds

C. Implementation of Circularity

The event scheduler and the basic network component objects in the data path are written and compiled using C++. These compiled objects are made available to the OTcl interpreter through an OTcl linkage that creates a matching OTcl object for each of the C++ objects and makes the control functions and the configurable variables specified by the C++ object act as member functions and member variables of the corresponding OTcl object. The backend files of the WiMAX module that are coded in C++ are modified to implement the principle of circularity. For Bandwidth request, we selectively drop the request packets. A counter is kept for the BWR packets scheduled to be sent by the SSs. When this counter value is a multiple of the circularity value, the corresponding BWR packet is dropped. In order to enhance the Bandwidth Request scheme, we make some modifications to the backend of ns-2, which is implemented in C++ language.

D. Implementation of Cyclic Prefix

NIST WiMAX patch supports Cyclic Prefixes up to 0.0625. Values can be varied in the tcl script initialization as shown.

Phy/WirelessPhy/OFDM set g_ 0.0625; # cyclic prefix

Valid prefix values are 0.5 (1/2), 0.25 (1/4), 0.125 (1/8), 0.0625 (1/16).By increasing the cyclic prefix, the overhead is increasing thus reducing the maximum throughput.

V. SIMULATION RESULTS

The simulations were run NIST WiMAX patch on NS-2.28 for varying sub stations. Using a simple C code, relevant details were extracted from trace file and delay involved is calculated and thereby throughput is also evaluated.

A. *Variation of Cyclic Prefix*

To evaluate the effect of varying Cyclic Prefixes on Network Performance we consider 12 sub stations and evaluate Throughput and Delay involved for 4 different Modulation Techniques supported namely, BPSK, QPSK. 16-QAM and 64-QAM.

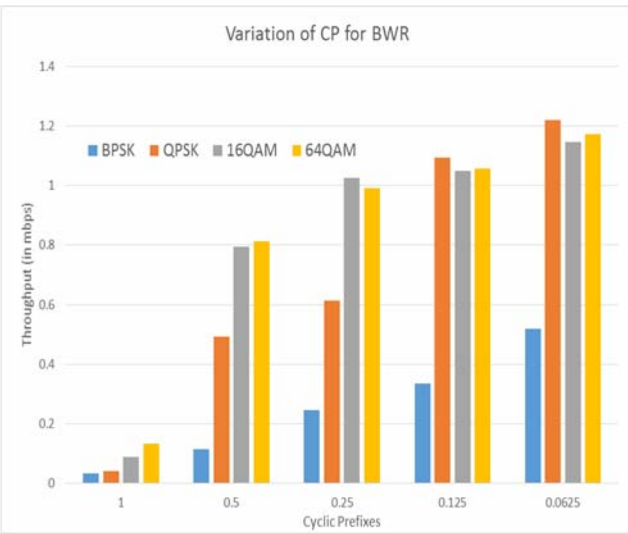

Fig.5. Throughput Comparison for CP Variation

Figure 5 shows the variation of Throughput against different Cyclic Prefixes for 4 different modulation techniques namely BPSK , QPSK , 16-QAM and 64-QAM.We can observe in the graph that Throughput is highest for Cyclic Prefix with value 0.0625 for all the 4 modulation techniques considered.

This is because transmission of cyclic prefix reduces the data rate and higher the value higher the overhead and lower the throughput. And Since OFDMA allows maximum of 16 sub-carriers CP of anything less than 1/16 will not have significant effect on the system. So, in the graph, as the CP value is decreased throughput increases for all 4 modulation techniques.

Figure 6 shows the variation of Delay against different Cyclic Prefixes for 4 different modulation techniques namely BPSK, QPSK, 16-QAM and 64-QAM.We can observe in the graph that Delay is least for Cyclic Prefix with value 0.0625 for all the 4 modulation techniques considered .Since higher CP value indicates higher overhead, delay involved is high as evident from the graph. So as CP value is decreased delay involved is also decreasing in the graph. So from these 2 graphs we can conclude that inserting Cyclic Prefix (CP) with value 0.0625 provides highest throughput and least delay out of all possible CP values.

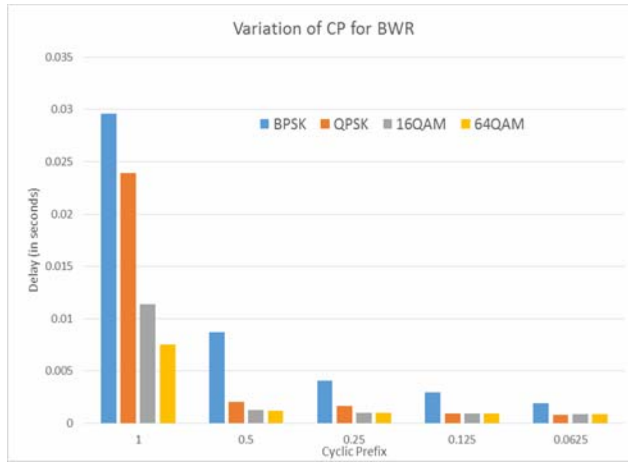

Fig. 6. Delay Comparison for CP Variation

B. *Variation of Circulariy*

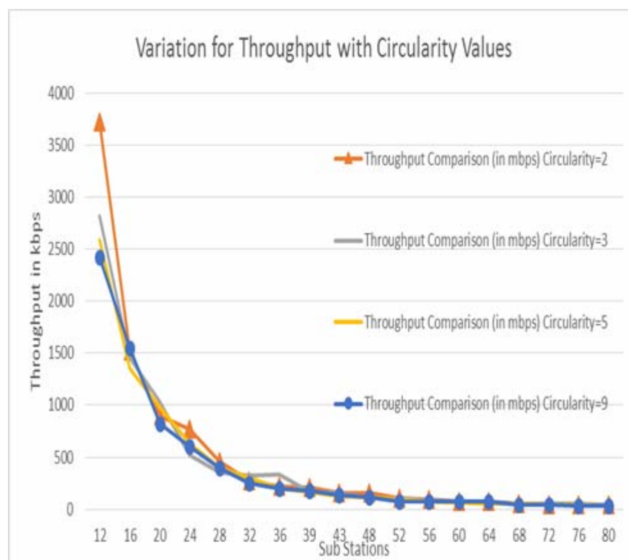

Fig..7. Throughput Comparison for Circularity Variation

To determine the effect of varying Circularity, simulations for varying sub stations and varying Circularities were carried out. We can observe from Figure 7 that Throughput is highest for lowest Circularity value of 2. Throughput is higher for lower Circularity values. So we use Circularity value of 2 for further simulations.

C. Comparison of Existing and Enhanced BWR Mechanism

Here we present results comparing existing BWR Scheme and Enhanced BWR Scheme after implementing Circularity value of 2 and Cyclic Prefix value of 0.0625.

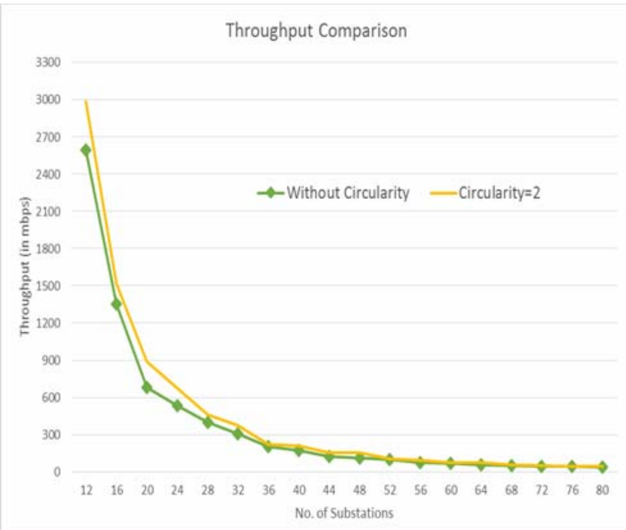

Fig. 8. Throughput Comparison of Existing and Enhanced BWR

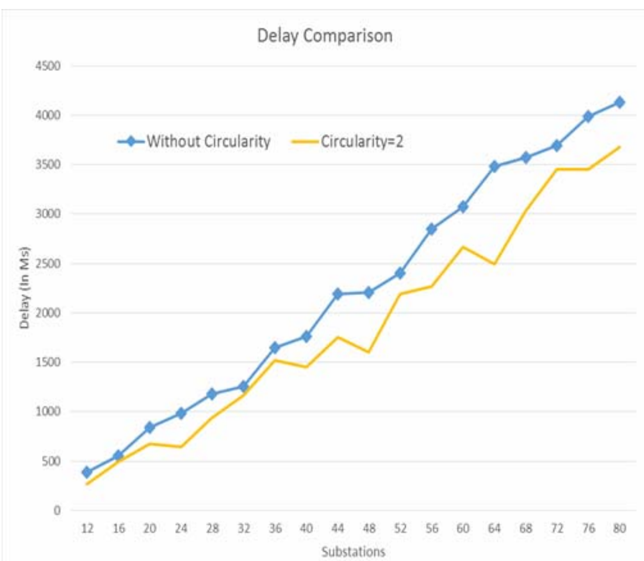

Fig. 9 Delay Comparison of Existing and Enhanced BWR

Figure 8 shows the variation of Throughput for 64-QAM modulation technique for existing BWR Scheme and the enhanced scheme with Circularity for varying sub stations. It is observed that as the numbers of sub-stations are increased, throughput decreases. This is because more the sub-stations more are the chances for packet collision and hence lower the efficiency of the network and thereby lower throughput as expected. Since the Enhanced Scheme curve stays above the Existing scheme curve, on average, we can conclude that there is an improvement in performance by about 21%.

Figure 9 shows the variation of Delay for 64-QAM modulation technique for existing BWR Scheme and the enhanced scheme with Circularity for varying sub stations. It is observed that as the numbers of sub-stations are increased, Delay increases. This is because more the crowded network is, high are the chances for packet collision and hence higher the delay. Since the Enhanced Scheme curve stays below the Existing Scheme curve we can conclude that a reduction In Delay has been achieved and thereby performance of IR has been improved by 16%.

VI. CONCLUSION

Bandwidth Request (BWR) is the process wherein the communication takes place between SSs and BS for uplink bandwidth allocation. We introduced the concept of circularity aiming to reduce collisions among the BWR packets and make better use of the contention slots. We carry out a frame analysis that shows the events that occur during the mechanism.

We have proved that the selective dropping of BWR packets decreases the number of collisions owing to improved mechanism of collision avoidance. This directly leads to decrease in the total access delay required by an SS to complete its BWR procedure. The throughput of the data sent is thereby considerably increased. Simulations also indicate lower the Circularity value, higher the throughput. Furthermore, we introduced Cyclic Prefix concept in BWR to improve the underlying modulation techniques. Hence, we can conclude that introduction of Circularity and Cyclic Prefix enhances the performance of BWR Mechanism.

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