Analysis and Enhancement of BWR Mechanism in MAC 802.16 for WiMAX Networks

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***Abstract*— WiMAX [Worldwide Interoperability for Microwave Access] is the latest contender as a last mile solution for providing broadband wireless Internet access and is an IEEE 802.16 standard. In IEEE 802.16 MAC protocol, Bandwidth Request (BWR) is the mechanism by which the Subscriber Station (SS) communicates its need for uplink bandwidth allocation to the Base Station (BS). The performance of the system is affected by the collisions of BWR packets in uplink transmission, that have the direct impact on the size of the contention period in uplink sub frame, uplink access delay and uplink throughput. This paper mainly deals with Performance Analysis and Improvement of Uplink Throughput in MAC 802.16 by the Application of a New Mechanism of Circularity. The implementation incorporates a generic simulation of the contention resolution mechanism at the BS. An analysis of the total uplink access delay and also uplink throughput is performed. A new paradigm of circularity is employed by selectively dropping appropriate control packets in order to obviate the bandwidth request collisions, which yields the minimum access delay and thereby effective utilization of available bandwidth towards the uplink throughput. This new paradigm improves contention resolution among the bandwidth request packets and thereby reduces the delay and increases the throughput regardless of the density and topological spread of subscriber stations handled by the BS in the network.**

Keywords- WiMAX, MAC 802.16 , BWR, NS-2, Tcl

I. Introduction

The IEEE 802.16 MAC layer plays an important role in the OSI model. It is a sub layer of the data link layer, the other being the logical link control layer (LLC), and acts as a link between the lower hardware oriented and the upper software oriented layers.

IEEE 802.16 consists of the access points like BSs (Base Station) and SSs (Subscriber Stations). All data traffic goes through the BS, and the BS can control the allocation of bandwidth on the radio channel. According to demand of subscribers stations Base Station allocates bandwidth. Hence 802.16 are a Bandwidth on Demand system. Basically there are two modes of operation in 802.16 i.e. P2MP (Point to Multi Point) and Mesh Mode of operation. In P2MP mode of operation a base station can communicate with subscriber station and/or base stations. Each SS is identified by a 48-bit IEEE MAC address and a BS is identified by a 48-bit Base Station ID (Not MAC address). Each connection with BS and SS in a session is identified by a 16-bit CID (Connection Identifier) In P2MP mode of operation communication between BS and SS is established based on Req / Grant mechanism (which is CSMA/CA in case of 802.11). In Mesh Mode operation a subscriber station can directly communicate with another subscriber's station within its communicating range. It is ad-hoc in nature [**1**].

We have considered the point-to-multipoint mode of operation of the IEEE 802.16 network. In this mode, the communication occurs only between the SS and the BS. The BS directly controls the data that is transmitted between the different SSs. In addition to the control of communication between SSs, a BS can send information to other BSs as well. This allows SSs that are not connected to the same BS, to exchange data. Initially when a SS is switched on, it performs the network entry procedure [**2**].

The procedure can be divided into the following phases:

- Scan for downlink channel and establish synchronization with the BS
- Obtain transmit parameters (from UCD message)
- Perform ranging
- Negotiate basic capabilities
- Authorize SS and perform key exchange
- Perform registration
- Establish IP connectivity
- Establish time of day
- Transfer operational parameters
- Set up connections

The following figure 1 shows the network entry procedure

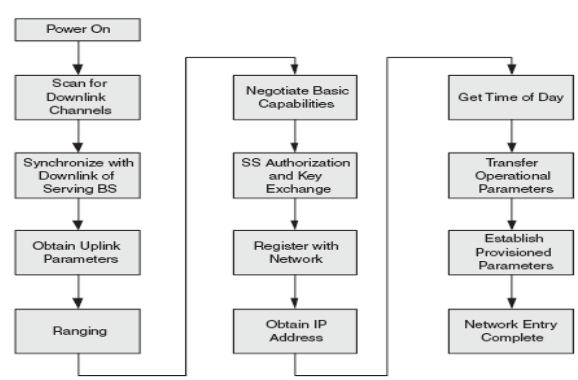

Figure 1

The BS in turn returns certain response messages in order to complete the different steps. The first such mechanism is Initial Ranging. Here, a series of Ranging-Request and Ranging-Response messages are exchanged. Also the processes of Negotiating Basic Capabilities and Registration involve their own request messages. These are called the SBC-REQ and REG-REQ messages respectively. After a SS has gained entry into the network of a BS, if it has data to send, it starts the Bandwidth Request (BWR) procedure. In our project, we focus on the contention-based BWR mechanism and its performance metrics [**3**].

A. Salient features of WiMAX

WiMax basically offers two forms of wireless service [**4**]:

1. **Non-line-of-sight**: This service is a WiFi sort of service. Here a small antenna on your computer connects to the WiMax tower. In this mode, WiMax uses a lower frequency range -- 2 GHz to 11 GHz (similar to WiFi).
2. **Line-of-sight**: In this service, where a fixed dish antenna points straight at the WiMax tower from a rooftop or pole. The line-of-sight connection is stronger and more stable, so it's able to send a lot of data with fewer errors. Line-of-sight transmissions use higher frequencies, with ranges reaching a possible 66 GHz.

The entire WiMax scenario is as shown in Figure 2.

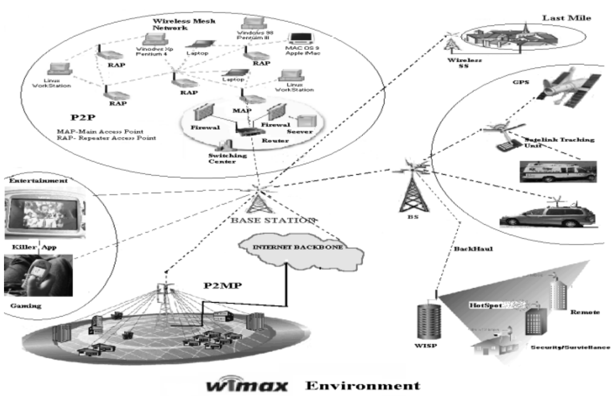

Figure 2

WiMax is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings. Some of the more salient features that deserve highlighting are as follows:

- OFDM-based physical layer
- Very high peak data rates
- Scalable bandwidth and data rate support
- Scalable bandwidth and data rate support
- Link-layer retransmissions
- Support for TDD and FDD
- WiMax uses OFDM

Flexible and dynamic per user resource allocation

II. STATEMENT OF THE PROBLEM

Bandwidth Request (BWR) is the mechanism by which the SS communicates its need for uplink bandwidth allocation to the BS. A single cell in WiMax 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 [**5**]. Bandwidth Request refers to the mechanism by which the SS ask for bandwidth on the uplink channel for data transmission. Compared to RNG-REQ, these request packets are of multiple types

They 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. This is because the uplink burst profile can change dynamically. There are two methods for sending bandwidth request. 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. 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 [**6**].

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 RACH method i.e. Random Access Channel 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: GPC (Grant per Connection Mode), GPSS (Grant per Subscribers Station), and Polling. 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 [**7**].

III. DESIGN SPECIFICATIONS

A. Analysis mode module

The purpose of this module is to analyze the communication between BS and SS's, and to obtain the access delay and Throughput of the network.

The following Network Architecture parameters are used for the simulation process.

- Number of Base Stations -1
- Number of Sink Nodes -1
- Number of Subscriber Stations – 6,12,…,60
- Traffic Start Time – 20 Sec
- Traffic Stop Time – 40 Sec
- Simulation Start Time – 0 Sec
- Simulation Stop Time – 50 Sec
- Channel Type – Wireless Channel
- MAC Type – Mac/802.16/BS

Along with the above network parameters, we also need to give the seed value for the simulation purpose. Seed value is actually taken by the Random Number Generation (RNG) process. There are 64 well-defined seed values available. We can find these seed values in network simulator application. By using these values we will carry out the simulation.

The parameters mentioned above are used in Tool Command Language script. Tcl scripting is used to design and simulate the WiMAX networks with varying architectures. Tcl gives us a lot of options that allow us to have a great degree of control over the simulation of networks. We use WiMAX Control Agent in order to produce a detailed account of the activities going on during the simulations.

Subscriber Stations (SSs) use the contention minislots for transmitting their requests for bandwidth. The Base Station allocates bandwidth for the SSs in the next frame, if bandwidth is available. Because of the reservation procedure, the SSs are guaranteed collision free data transmission. The contention is resolved in the uplink channel for bandwidth request based on a truncated binary exponential backoff, with the initial backoff window and the maximum backoff window controlled by the base station (BS). The values are specified as part of the Uplink Channel Descriptor (UCD) message, describe the physical layer characteristics of an uplink and are equal to power-of-two. The SS will enter a contention resolution process, if it has data for transmission.

Figure 3 shows the contention resolution process for this module.

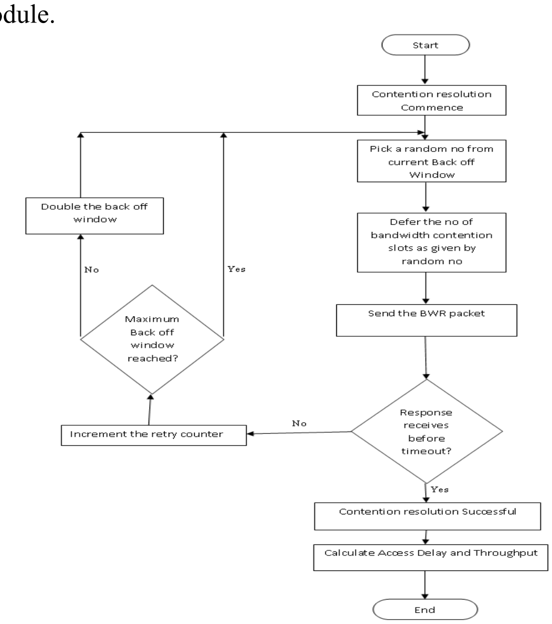

Figure 3

B. Enhancement mode module

The purpose of this module is to analyze the communication between BS and SS's, and obtain the delay incurred in BWR and Throughput of the network by using Circularity Principle. For this Module, the Network Architecture parameters are the same as we set up in Analysis mode. We use these parameters in Tool Command Language. In addition to this, we have to input, Circularity value which is needed to carry out the enhancement process. Here we need to set this value at the back-end of the network simulator.

Figure 4 shows the contention resolution process for this module. The procedure is same as we see in the previous module but only difference is, here we are enclosed the new Circularity principle. Circularity concentrates on the modification of existing BWR scheme so as to minimize BWR collisions and hence improving the throughput [**8**].

Circularity is defined as a number which enables the identification of specific groups of events or packets. Each event or packet under consideration is numbered in a sequential manner. An event or packet with a number which is a multiple of the circularity value is said to be circularity-satisfied. So we are setting a counter to find Circularity satisfied packet and we are dropping it. So, a finite delay is introduced before the occurrence of circularity satisfied events or the sending of circularity satisfied packets. This additional delay reduces the probability of packet collisions. The selfless behavior of certain SSs may increase the individual BWR delays but on the whole the delay incurred in the entire network will be reduced. All the other calculation remains the same as we see in Analysis module.

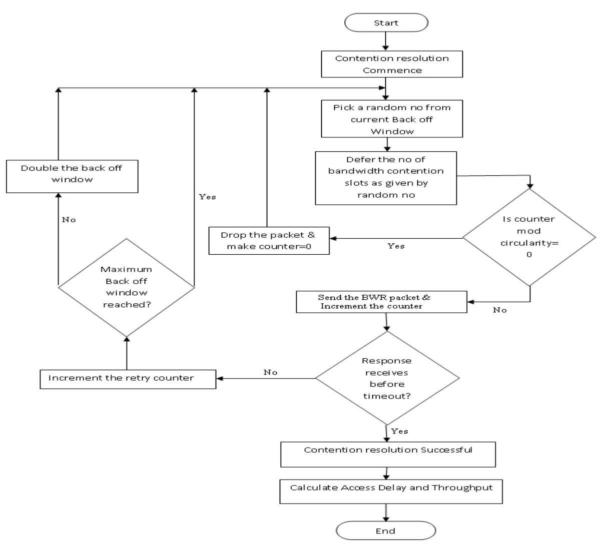

Figure 4

C. Comparison mode module

The purpose is to analyze the graph which shows that how the Enhancement mode is better than the existing scheme. For this Module, the Network Architecture parameters are the same as we set up in Analysis mode. We use these parameters in Tool Command Language. In addition to this, we have to input, Circularity value which is needed to carry out the enhancement process. Here we need to set this value at the back-end of the network simulator.

In this module, we are comparing the results of two previous modules. Before the processing of this module, we need to run the simulation by setting different number of mobile nodes for analysis and enhancement modules and note down the results. The obtained delay and throughput results are written in a file. The extension of this file should be filename.xg and need to input to the Xgraph package to plot the graph. The output file will be an image file of the extension png. Figure 5 shows the flow chart for comparing the Access delay results of two previous modules.

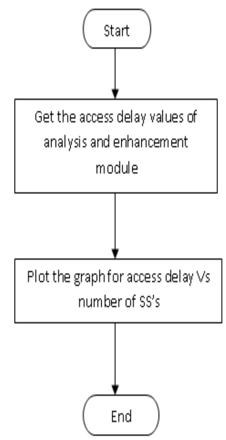

Figure 5

Figure 6 shows the flow chart for comparing the Throughput results of two previous modules.

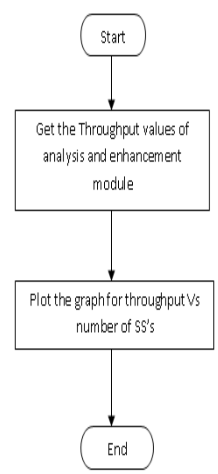

Figure 6.

IV. HARDWARE AND SOFTWARE REQUIREMENTS

A. Hardware Interface

- Pentium 4 processor.
- 512 MB RAM.
- 20 GB Hard Disc Memory

B. Software Interface

- Network Simulator 2 (ns-2)
- TCL (Tool Command Language)

1) The Network Simulator 2 (NS2): NS2 is a tool that helps you better understand certain mechanisms in protocol definitions, such as congestion control, that are difficult to see in live testing [**9**]. It is recommended NS2 as a tool to help understand how protocols work and interact with different network topologies. We can also patch the source code in case the protocol you want to simulate is not supported and live with low-quality graphics tool [**10**]. Figure 7 shows the network animator.

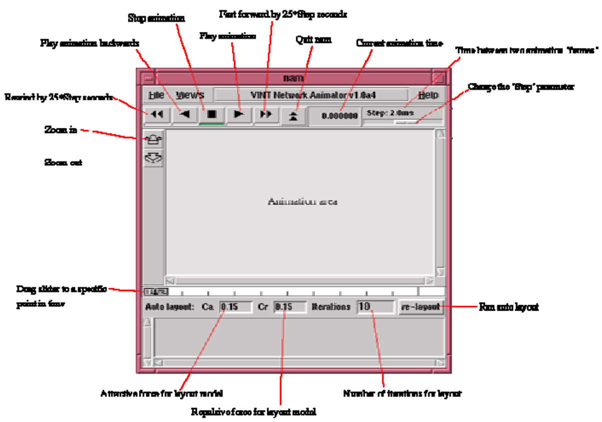

Figure 7

2) TCL (Tool Command Language)

Tcl is a small language designed to be embedded in other applications (C programs for example) as a configuration and extension language [**11**]. Tcl is specially designed to make it extremely easy to extend the language by the addition of new primitives in C. Like Lisp, Tcl uses the same representation for data and for programs.

V. SIMULATION SETUP

The Simulation consists of two parts:

- Simulation of BWR scheme without Circularity using NS-2
- Changing the backend and re-simulating (With circularity)

The following parameters are used for the simulation of the existing Bandwidth Request scheme.

- Channel Type – Wireless Channel
- Radio Propagation Model– TwoRayGround
- Network Interface Type Phy/WirelessPhy/OFDM
- MAC Type – 802_16
- Interface Queue Type – DropTail Priority Queue
- Link Layer Type – LL
- Antenna Model – Omni Antenna
- Maximum Packets in Interface Queue – 50
- Routing Protocol – DSDV (Routing is done through the Base Station)
- Routing Protocol- AODV (Routing is done through the Base Station)
- Network Architecture Parameters:
- Number of Base Stations – 1
- Number of Sink Nodes – 1
- Number of Subscriber Stations – Varied from 4 to 64
- Base Station Coverage – 20 meters
- Traffic Start Time – 20
- Traffic Stop Time – 40
- Simulation Stop Time – 50

A. Simulation of BWR Scheme without Circularity

The parameters mentioned are used in the Tool Command Language (TCL) script that we have written. This script also uses the WiMAX Control Agent in order to produce a detailed account of the activities going on during the simulations. In the resulting output file, we search for the timing details of specific events in order to extract the Bandwidth Request delay.

The start and stop traffic times of the BWR procedure for all the Subscriber Stations (SS) in the scenario are stored in files. Using a C program, we find the average BWR delay per node, after calculating the total time taken by all the nodes to complete their respective BWR processes.

Such simulations can be carried out for different numbers of SS each time by the use of shell scripts. Then the average BWR delay is recorded along with number of SS involved in each such simulation.

B. Changing the backend and re-simulating (With circularity)

In order to enhance the Bandwidth Request scheme, we make some modifications to the backend of ns-2, which is implemented in C++ language. During the BWR procedure, there will be many SS contending to send their requests to join the network. The packets sent by different SS may collide at some instants and they will have to be resent. We try to reduce the collisions between packets of different SS by making the SSs less selfish. We have made two such changes, one in each of the files mentioned above [**12**].

VI. RESULTS

We have run the simulation for 6 mobile nodes and we can see the output as in the figure 8. The calculator function takes the traced file, track the sent times details and stored in the intermediate file by name sent times-f. The figure 9 shows the screenshot of sent time details.

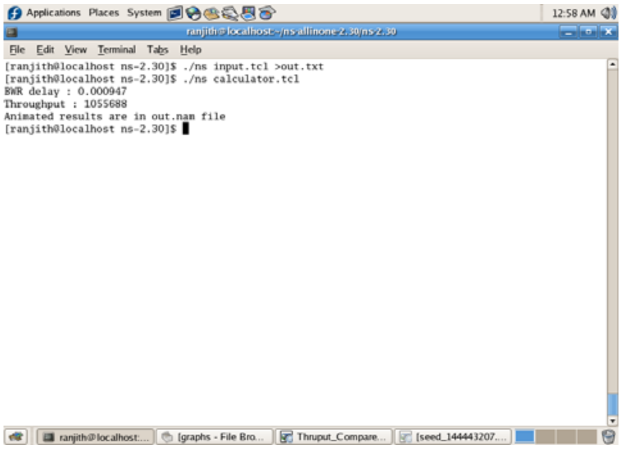

Figure 8

The calculator function takes the traced file, track the received times details and stored in the intermediate file by name recvtimes-f. The figure 10 shows the screenshot of Received time details.

A. *Comparison of access delay (For single instance)*

- Input given: Seed value = 144443207.
- No. Of SSs=6, 12, 18……….60.
- WOC: Without circularity
- WC: With Circularity

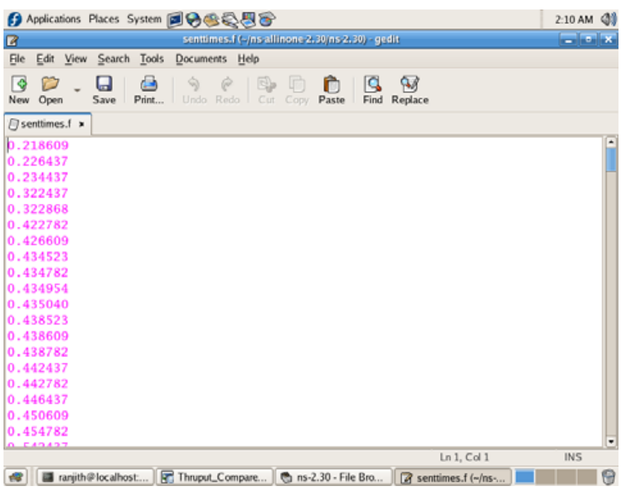

Figure 9

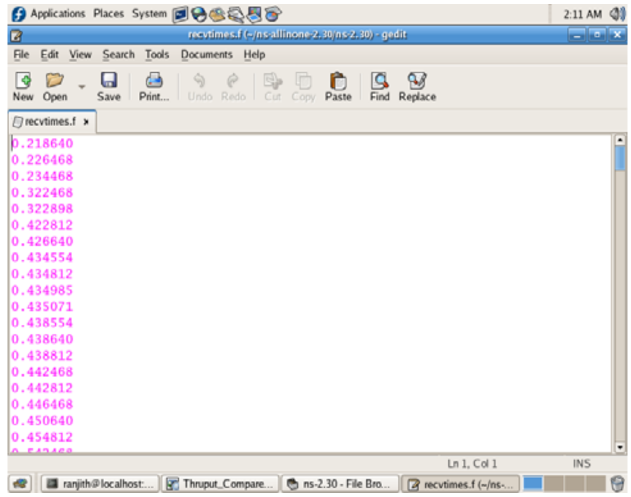

Figure 10

The outputs for the following sequence of subscriber stations (SSs) with and without circularity are observed and as shown in table.1

Table.1

SSs	WOC Access delay In seconds	SSs	WC Access delay In seconds
6	0.000929	6	0.000930
12	0.001000	12	0.000998
18	0.001016	18	0.001010
24	0.001019	24	0.001015
30	0.001023	30	0.001018
36	0.001028	36	0.001021
42	0.001035	42	0.001027
48	0.001060	48	0.001056
53	0.001066	53	0.001098
54	0.001070	54	0.001098
60	0.001104	60	0.001098

Figure 11 shows the graph of Access delay across various size of network with and without circularity.

We can see that, access delay is reduced in the case of enhanced network where we used the concept of circularity. As we see in the graph, the delay is gradually increased for both existing and new plans. But, we find there is better performance with the new scheme.

X-axis: No. Of subscriber stations   Y-axis: Delay

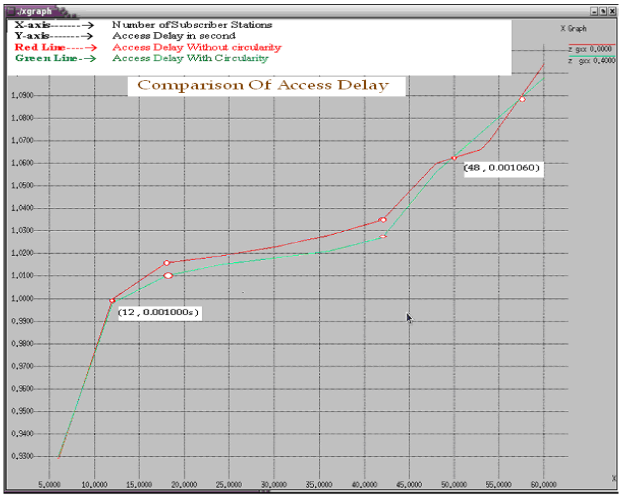

Figure 11

We have marked the two points in the graph where the two lines are crossed each other. At first point, the two lines start diverging from each other. It will cross each other once again at the second time where the network size increased.

B. *Comparison of Throughput (For single instance)*

- Input given: Seed value = 144443207.
- No. Of SSs = 6, 12…60.
- WOC: Without circularity
- WC: With Circularity
- TPT: Through put

The outputs for the following sequence of subscriber stations (SSs) with and without circularity are observed. The comparison of throughput is as shown in table 2.

Table.2

SSs	WOC TPT in Bits Per Second	SSs	WC TPT in Bits Per Second
6	8611410	6	8602150
12	8000000	12	8016032
18	7874015	18	7920792
24	7850834	24	7881773
30	7820136	30	7858546
36	7782101	36	7835455
42	7729468	42	7789678
48	7547169	48	7575757
53	7504690	53	7575757
54	7476635	54	7575757
60	7246376	60	7285974

The figure 12 shows the graph of comparison of the Throughput of the network by taking different number of SSs with and without circularity.

X axis: No. of subscriber stations Y axis: Throughput

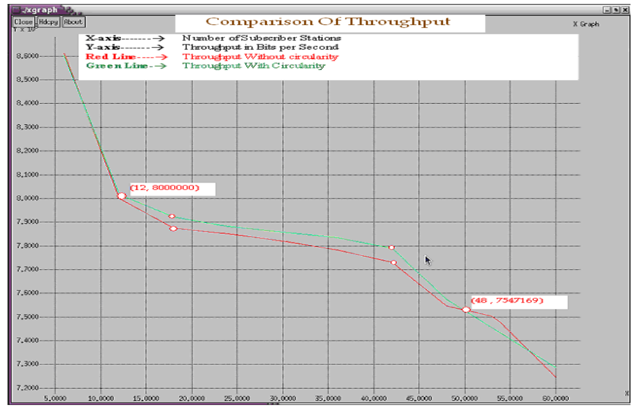

Figure 12

We can see increased Throughput in the case of enhanced network where we used the concept of circularity. In the above graph we can see that two times the two lines are crossed each other. We can see decreased throughput for the network where we included the concept of circularity. At the first co-incident point, the network size is less and the second time, the network size is increased.

C. *Comparison of access delay (For 10 trials output)*

When the results were run for 10 different seed value and the average is taken for each subscriber stations (SSs), for both with and without circularity we obtain the following graphs as shown in figure 13.

X-axis: No. of subscriber stations & Y-axis: Access Delay

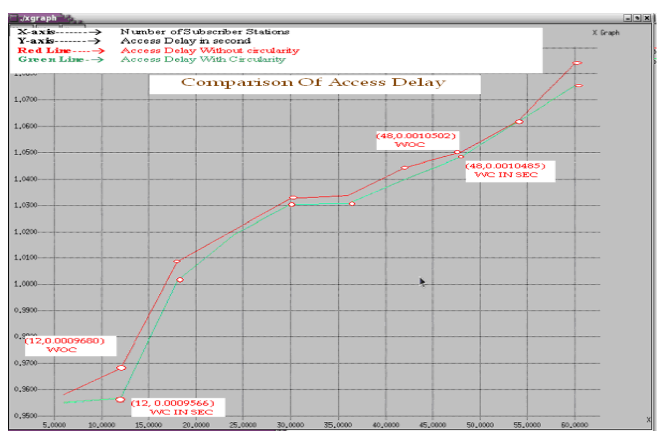

Figure 13

We can see that delay is decreased in the case of circularity implemented network.

D. Comparison of Throughput (For 10 trials output)

Figure 14 shows the comparison of throughput for both with and without circularity of 10 trials.

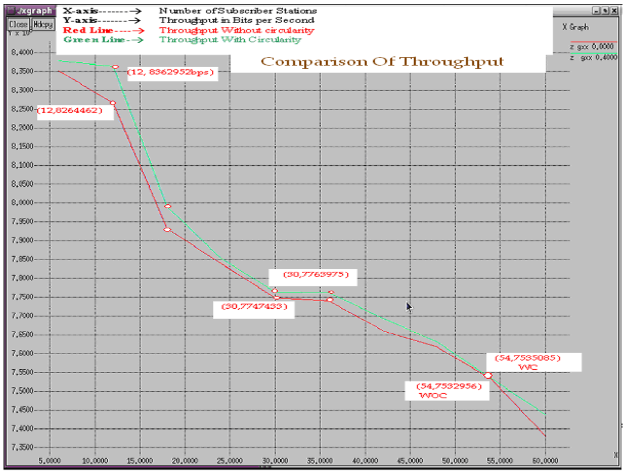

Figure 14

In figure 14 we have calculated the throughput from the previous access delays, which have been taken for ten trials. We can see the better performance in the case of circularity.

VII. CONCLUSION AND FUTURE ENHANCEMENT

The project involves the design of MAC IEEE 802.16. Here, new concept of circularity has been included in the existing contention resolution algorithm for MAC 802.16. In the existing MAC layer, there is certain amount of wastage in the available bandwidth. A concept of circularity is introduced whereby selected BWR slots are dropped in a controlled way in our new enhanced MAC protocol. We have seen the results of minimized uplink access delay, improved throughput and there by reduction in contention slots per frame. Hence circularity principle can be used to enhance the performance of MAC 802.16. We tried to reduce the collisions and hence have shown that concept of circularity can lead to higher throughput on an average of 12% more than the normal. For current design we have assumed the circularity on all SSs. This scheme can be modified in some particular SSs wherein we apply circularity concept to establish it is also more efficient than this scheme.

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