Channel Aware Uplink Scheduler for a Mobile Subscriber Station of IEEE 802.16e

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ABSTRACT
The scheduling part of the IEEE 802.16 (WiMAX) standards is kept as an open issue to provide differentiation among equipment manufacturers and operators. The uplink scheduling is very significant and more complex compared to downlink scheduling. Uplink scheduling is divided into two parts; one is scheduling the resources among many users from a base station (BS) and the other is sharing the resources among its services in a single user. BS uplink scheduling has been given more attention compared to subscriber station (SS) uplink scheduling. SS scheduler plays a significant role in providing the quality of service (QoS) among its services. The channel status awareness is vital in designing the SS scheduler as the channel conditions vary for a mobile user. This work proposes a scheduling algorithm for SS, which utilizes the channel information and queue length variation for the reallocation of received aggregated bandwidth grant to optimize the QoS parameters. The performance of the proposed algorithm is studied by conducting simulations using QualNet 5.0.2 simulation tool. Simulation results demonstrate the effectiveness of the proposed algorithm to improve the QoS.

Keywords
Channel aware, IEEE 802.16e, QoS, SS, Uplink scheduling, WiMAX

1. INTRODUCTION
Mobile communication has experienced an exponential growth in the usage, services and applications; worldwide interoperability for microwave Access (WiMAX) has witnessed a tremendous growth and evolved as one among the potential broadband wireless access (BWA) technology. The IEEE 802.16e [1-2] introduces the mobility and a user can access the network ubiquitously. This standard supports orthogonal frequency division multiple access (OFDMA) together with adaptive modulation and coding (AMC) to enhance the system performance over the error prone wireless channel. Different modulation and coding schemes (MCS) are adopted by the subscriber station (SS) on the basis of detected instantaneous signal to noise ratio (SNR) as the SS moves away or toward the base station (BS). There is a possibility of deterioration of quality of service (QoS) for real time services as the channel quality varies. The SS gets an aggregate bandwidth allocated to all its services, which is typically a grant per subscriber station (GPSS) type of bandwidth grant. SS needs to be proficient enough to handle the resources and should adapt a bandwidth handling mechanism between its real time and non real time services with the variation in channel conditions, hence a scheduler is essential for SS. The SS can use scheduling information embedded in it to enforce the QoS for the different multimedia services generated by it. This work attempts to design one such channel aware and distributed uplink scheduler, which resides at the SS.

An extensive literature survey in this area is reported. Proposing new algorithms is a hot research topic in WiMAX, as the scheduling algorithms for BS and SS are not defined by the standard [1]. However, most of them concentrate on the QoS architecture and uplink scheduler of BS [3-8]. Authors of [9-12] have focused on downlink scheduler design of BS. Scheduling algorithms for SS are not handled well, some conceptual scheduling algorithms proposed in [13-15] with no or trivial validations. The wireless medium is pretty random and uncertain in nature and this makes the channel status and channel behavior as an essential design parameter for the scheduler. The authors in [16-19] focused on channel variation, but these schedulers are presented for BS side. However authors of [20] presented a novel resource allocation scheme at both BS and SS but without any channel awareness. Chakchai So-In et.al [21] have done a survey on scheduling algorithms. A detailed performance evaluation of scheduling algorithms is presented in the thesis [22]. A scheduling architecture for a SS with classical scheduling algorithm suited with fixed scenario is proposed in [23]. Authors of [24] offered a priority-based fair scheduling algorithm for SSs to serve a mixture of uplink traffic from different scheduling service. Sun Zhen Tao et.al [25] have investigated the uplink scheduling at SS and suggested an algorithm intelligence bandwidth allocation of uplink (IBAU) but without any performance evaluation. Authors of [26] advised a cross-layer designed scheduling algorithm called dynamic MCS and interference aware scheduling algorithm (DMIA) for the uplink of WiMAX and evaluated the performance of the algorithm using ns2.

The structure of the paper is as follows, Section 2 gives the background and Section 3 details about the QoS mechanism of IEEE 802.16 standard. Section 4 explains the proposed algorithm for SS. The effectiveness of the proposed algorithm is demonstrated by simulation results in Section 5. Finally the work of this paper is concluded.

2. BACKGROUND

WiMAX is the IEEE 802.16 standard-based BWA technology intended for metropolitan area networks (MAN), which defines air interface for fixed and mobile BWA systems. The IEEE 802.16 standard includes MAC and PHY layer specifications and it is designed to achieve goals like easy deployment, high speed data rate, large spanning area and large frequency spectrum. Initially, 802.16a adopted OFDM PHY, which provides greater spectral efficiency and better mitigation of interference with the range of frequency 2-11 GHz and non-line of sight (NLOS) communication. The 802.16b covers most of the QoS aspects. 802.16d (802.16-2004) was a revised version of the 802.16. The 802.16e was developed to support mobile BWA with requirements to support the wireless communication at vehicular mobility and seamless handover while maintaining differentiated QoS. IEEE 802.16 standard supports point to multi point (PMP) mode and mesh mode. The PMP mode follows a centralized architecture of data transmission in which all the SSs communicate via BS. However in mesh mode of operation the SS can directly communicate with its peers, this work concentrates on PMP mode. The WiMAX MAC accommodates two classes of SS that are differentiated by their ability to accept bandwidth grants for a single connection or for the SS as a whole. Both classes of SS request bandwidth per connection to the BS. The two classes are grant per connection (GPC), where the BS grants bandwidth explicitly to each connection and GPSS, where bandwidth is granted to all connections belonging to the station. There is no need of an exclusive scheduler at SS in case of GPC mode, as BS schedules the services of SS. On the contrary in GPSS mode, SS decides how the redistribution of bandwidth can be done among its services, while maintaining the QoS and service-level agreements (SLA). Hence an intelligent scheduling mechanism should exist at SS in GPSS mode. Scalable OFDMA (SOFDMA) was introduced to support scalable channel bandwidths from 1.25 to 20 MHz, which provides true QoS. Mobile WiMAX (802.16e) is equipped with novel technological tools, such as OFDMA, time division duplexing (TDD), frequency division duplexing (FDD), multi-input multi-output (MIMO), AMC, internet protocol (IP), security and others, which are combined together to offer high-rate, low-cost, wide-area, secured mobile multimedia services. Under downlink QPSK, 16QAM and 64QAM modulation schemes are used whereas in the uplink 64QAM is optional and rest of the modulation schemes are used.

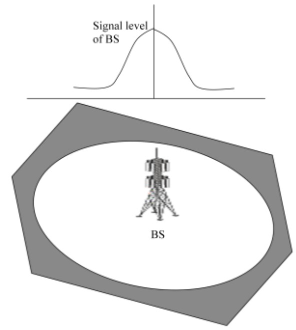

Fig.1.Variation of BS's signal strength

Fig.1 reveals that when the SS moves with vehicular speed, the received signal strength varies depending upon the direction of movement towards or away from BS. Under such conditions, the GPSS bandwidth grant obtained by SS in each frame needs to be utilized properly. Invariably the SS with bad channel condition gets less amount of bandwidth from BS or less attention of BS. The scheduler at SS redistributes its bandwidth among real time and non real time services without affecting the service level agreements and QoS.

3. IEEE 802.16e QoS MECHANISM

IEEE 802.16 defines two channels, uplink (SS to BS) which is shared by multiple SSs and downlink (BS to SSs) which is broadcasting. The frame size is fixed and divided as two parts uplink and downlink subframes. There are two modes of duplexing techniques; TDD in which uplink and downlink subframes are transmitted at different times. However in FDD scheme uplink and downlink subframes can be transmitted simultaneously but at different frequencies. This work considers only TDD mode. In the uplink subframe BS determines the number of time slots for each SS to transmit and this information is broadcasted by BS through uplink map (UL-MAP) message. Uplink packet scheduling (UPS) and the admission control modules provide QoS provision at BS.

Admission control module handles the initial connection establishments including handshaking connection requests and response on the start of communication between SS and BS.

Table 1.WiMAX services and QoS requirements

QoS service class	**Application**	**QoS specifications**
UGS (Unsolicited grant service)	VOIP, T1/E1	Minimum reserved rate, Maximum sustained rate, Traffic priority, Maximum latency tolerance
ertPS (Extended real time polling service)	Silence suppressed VOIP	Minimum reserved rate, Maximum sustained rate, Traffic priority, Maximum latency tolerance, Jitter tolerance
rtPS (Real time polling service)	Streaming audio or video, Tele medicine, E-learning	Minimum reserved rate, Maximum sustained rate, Traffic priority, Maximum latency tolerance
nrtPS (Non real time polling service)	FTP, document sharing	Minimum reserved rate, Maximum sustained rate, Traffic priority
BE (Best effort)	Web browsing, E-mail	Maximum sustained rate, Traffic priority

Upon acceptance of a connection by the admission control, subsequently the UPS module decides bandwidth granted for a station depending on its bandwidth requirement and to full fill its QoS requirement. Once after getting an aggregate bandwidth grant from BS, the SS has to reallocate and redistribute the bandwidth among its service types. Table 1 shows the QoS services defined by WiMAX and the QoS parameters required for them.

As it has been mentioned earlier the real time services have more rigid QoS requirements in order to meet the delay requirements and hence are mapped on high prioritized scheduling services like UGS, ertPS and rtPS. Nevertheless the non real time services required to be throughput optimal, therefore a proper balance of resource management between real time and non real time services should be maintained to effectively utilize the bandwidth assigned to each SS resulting in the performance enhancement of the entire system.

4. PROPOSED ALGORITHM

The proposed algorithm for the SS scheduler depends on the PHY layer of IEEE 802.16e WiMAX with AMC to optimize the resource management. Different MCS are adopted by the SS based on detected SNRs. Table 2 lists the MCSs used in this work, MCS k is adopted if the detected instantaneous SNR is in the range [Γ_k, Γ_{k+1}]. If the detected SNR is less than Γ_1 (5.6dB), due to the unbearable transmission error, data is not transferred. It can be noticed that the raw data rate varies depending on the MCS at a particular instant.

Table 2. Modulation and coding schemes

k	**Modulation**	**Encoding Rate**	**Number of symbols**	**Raw Data Rate (Mbps)**	**SNR Γ_k (dB)**
1	QPSK	1/2	2	14.2875	5.6
2	QPSK	3/4	2	21.4285	9
3	16QAM	1/2	4	28.5714	11.48
4	16QAM	3/4	4	42.8570	15
5	64QAM	1/2	4	42.8570	17.02
6	64QAM	2/3	6	57.1428	19
7	64QAM	3/4	6	64.2857	21

The WiMAX standard defines a channel quality indicator (CQI) to report channel state information (CSI). In turn this includes the mean and standard deviation values of effective carrier-to-interference-and-noise ratio (CINR) and receive signal strength indicator (RSSI). These values are sent to BS to aid the process of AMC selection. After receiving the CSI, BS broadcasts downlink channel descriptor (DCD) and uplink channel descriptor (UCD) with forward error correction (FEC) to notify the MCS to be followed by SS [27]. This channel status can be used to handle the bandwidth redistribution among its connections at the SS in GPSS mode. This work makes an attempt to utilize channel information to design of proposed algorithm for the SS's aggregate packet scheduler.

In BS admission control, a maximum sustained rate (MSR) is assured for real time services and minimum reserved rate (MRR) is guaranteed for non real time services. Therefore the connections are admitted by BS, if it has the budget to fulfill the above said condition. In GPSS mode, SS obtains the aggregate bandwidth grant for all its requested connections. Being standard compliant, in this implementation UGS traffic is not taken in to consideration. Rest of the service types are divided in to two types; real time services (RTS) which include ertPS and rtPS scheduling services and the non-real time services (NRTS) consist of nrtPS and BE scheduling services. The scheduler provides a fair resource allocation among RTS and NRTS.

The strong reasons of having a GPSS based architecture is to mainly handle a distributed resource allocation at SS and to reduce the overhead of BS. This can be accomplished by having a suitable bandwidth handling mechanism among the existing connections at SS. This can be explained as follows.

$$B_T = B - B_{UGS} \quad (1)$$

Where B is the bandwidth assigned to SS aggregate scheduler, B_T is the remaining bandwidth after assigning B_{UGS} bandwidth to UGS services.

$$B_T = B_{RTS} + B_{NRTS} \quad (2)$$

$$B_{RTS} = B_{ertPS} + B_{rtPS} \quad (3)$$

$$B_{NRTS} = B_{nrtPS} + B_{BE} \quad (4)$$

B_{RTS} and B_{NRTS} define the bandwidths assigned to real time and non-real time services respectively. In turn B_{RTS} includes bandwidths granted for ertPS and rtPS services and B_{NRTS} includes bandwidths assigned for nrtPS and BE service types. In the proposed algorithm, the channel condition is categorized into three levels based on the instantaneous SNR and MCS at which the SS is working; those are *Good*, *Intermediate* and *Bad* channel condition illustrated in Fig.2 Channel condition categorization is explained as follows. The flow chart of proposed algorithm is given in Fig. 3.

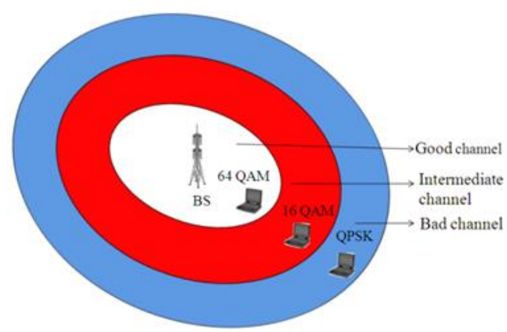

Fig.2. Channel categorization using AMC and MCS

4.1 Good channel

When the SS is using 64QAM is assumed as a *Good* channel condition. As per table 2, 64QAM provides the good data rate and hence is capable to suffice the QoS requirement of all the admitted connections. Bandwidth is requested according to the requirement of a connection. But it is observed that RTS data traffic is variable bit rate (VBR) in nature and hence incoming data rate also varies. To determine the rate at which incoming traffic arrives at the scheduler, queue length variation Q_v (equation 5) is taken in to account for different service types of i. Where i=1 represents ertPS service type and i=2, 3, 4 corresponds to rtPS, nrtPS and BE service types.

$$Q_v(i) = Q_{pres}(i) - Q_{prev}(i) \quad (5)$$

This measure can be used to plan the bandwidth reallotment among all services. Unlike predicting the future bandwidth requirement of a service type [28] and making an extra or less bandwidth request to BS, in this work it is more emphasized on the reallocation of already received aggregated bandwidth grant. This reallocation procedure is based on queue length variation and threshold based bandwidth assignment. Queue length variation can go up to a maximum value of queue buffer size. To decide the threshold values, queue length variation is divided into n levels; the following equation briefs the threshold value selection. Here *L* is maximum buffer size of a queue.

$$T_j = \frac{L * j}{n} \qquad \forall j = 1,2...,n \quad (6)$$

Each threshold level is ensured with a bandwidth based on its delay tolerance limit for RTS. For RTS the queue length variation is checked for its threshold level and it is allocated with the bandwidth ensured by that threshold level. The remaining bandwidth is distributed among the NRTS according to queue length variation.

4.2. Intermediate channel

If the SS is working on 16QAM is considered as *Intermediate* channel, this provides the moderate data rate. It can be noticed from table 2 that the symbols carried on 16QAM lie between the symbols carried by 64 QAM and QPSK, therefore the data rate of this modulation is moderate and hence it can be considered as intermediate channel level. Under this channel condition all the service flows are atleast guaranteed with MRR. The SS scheduler checks the bandwidth requirement of each flow based on the queue size and gives priority to RTS than NRTS. RTS are allocated with the required bandwidth according to the priority and the remaining bandwidth is given to NRTS based on priority.

4.3. Bad channel

The SS working at QPSK is considered as *Bad* channel condition, this modulation is adapted when the SNR is low, since QPSK is a robust modulation. In the meantime the data rate is very low. Under this channel condition all the service flows are at least guaranteed with MRR. The SS scheduler checks the bandwidth requirement of each flow based on the queue size and gives priority to NRTS than RTS. NRTS are allocated with the required bandwidth according to the priority and the remaining bandwidth is given to RTS based on priority.

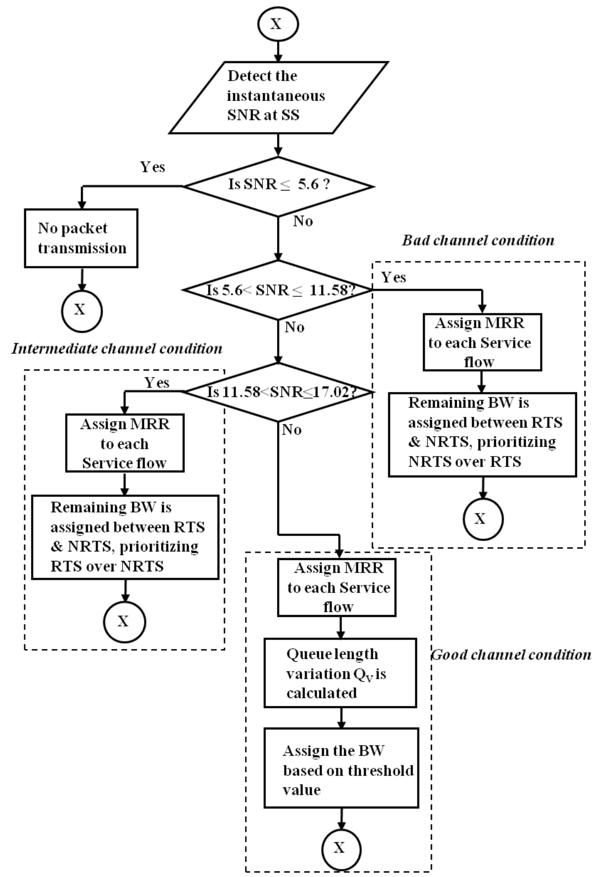

Fig.3. Flow chart of proposed algorithm

5. SIMULATION AND RESULTS

An extensive simulation study is performed for the proposed and implemented scheduler using QualNet 5.0.2 [29]. Simulation scenarios are designed to test the effectiveness of the proposed algorithm. A single WiMAX cell is considered in the simulation area of 4Km x 4Km, working at a frequency 2.4GHz. The path loss model selected is two ray with constant shadowing model of shadowing mean 4dB. In a single frame the downlink to uplink duration ratio is considered as 2:1. The basic admission control scheme is used for admitting the connections at the BS. The simulation parameters settings are mentioned in Table 3 and traffic is generated according to Table 4.

Table 3.Simulation parameters

Property	Value
Simulation time	100 Sec
Channel bandwidth	20 MHz
FFT size	2048
Antenna model	Omni directional
BS antenna gain	10 dBi
SS/MSS antenna gain	0 dBi
BS antenna height	12 m
SS/MSS antenna height	1.5m

Table 4.Traffic generation for simulation

Service Type	Maximum Sustained Data Rate in Kbps	Minimum Reserved Data Rate in Kbps
UGS	64	64
ertPS	64	8
rtPS	3072	1024
nrtPS	3072	1024
BE	1024	0

5.1. Scenario 1

In this scenario a single BS and six SSs (five are stationary and one is mobile) are considered. The uplink performance of the mobile SS (node 3) is evaluated, since it is transmitting all kinds of traffics like UGS, ertPS, rtPS, nrtPS and BE. As the performance of aggregate scheduler is to be evaluated, multiple connections are not used in a particular service type, as multiple connections in a service type are scheduled following the weighted fair queuing (WFQ) algorithm [28]. Screenshots (Fig.4 and Fig.5) captured from QualNet tool describe the above description, simulations are performed for two conditions; one for SS moving away from the BS (Fig.4) and in the other SS moving towards the BS (Fig.5) with a velocity of 20m/s. Simulation results illustrate the throughput and delay performance of RTS and NRTS with respect to the SNR (Fig.6-9).

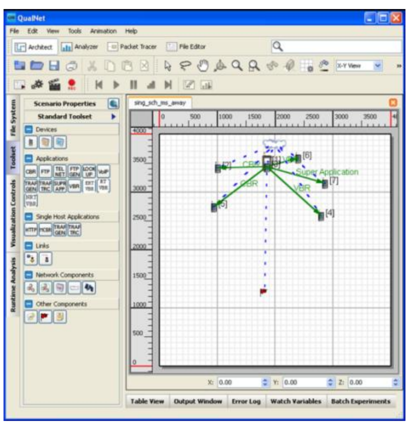

Fig.4.Single SS moving away from BS

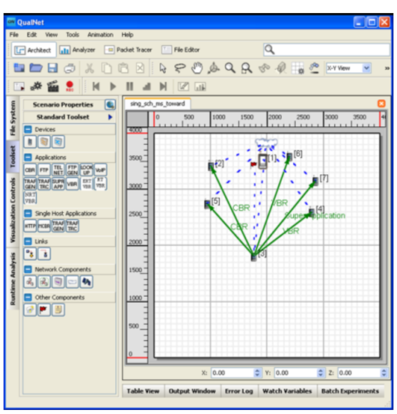

Fig.5.Single SS moving towards BS

5.1.1 SS moving away from BS

If a SS moves away from BS (Fig.4), as the simulation time progresses it passes through intermediate channel condition and finally reaches bad channel condition. Fig.6 and Fig.7 demonstrate the delay and throughput performances respectively. Results are plotted to compare the implemented work with no implementation for RTS and NRTS. Delay performance of implemented work outperforms no implementation results under all the channel conditions.

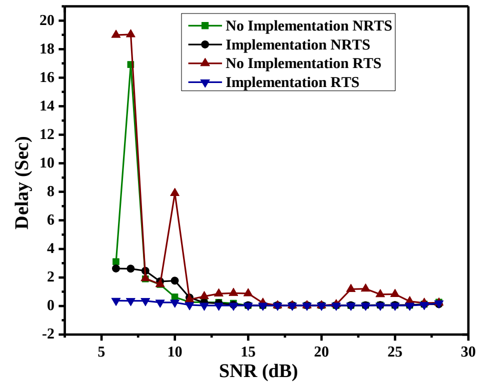

Fig.6.Delay performance of RTS and NRTS services

It is observed that as the SS reaches bad channel condition delay is more for RTS and NRTS, but with proposed algorithm it is considerably less. On the other hand throughput performance becomes optimum for implemented work. Initially when SS starts moving away from BS slowly throughput starts increasing and when it reaches bad channel condition throughput decreases. Because the bandwidth distribution adopted under good channel condition depends on queue length variation and the well defined threshold level based bandwidth allocation, which gives an enhanced delay performance with favorable throughput performance. Under intermediate channel and bad channel conditions the bandwidth allocation method is entirely queue length based with guaranteed MRR. These mechanisms aid in attaining a bounded delay and stabilized throughput performance.

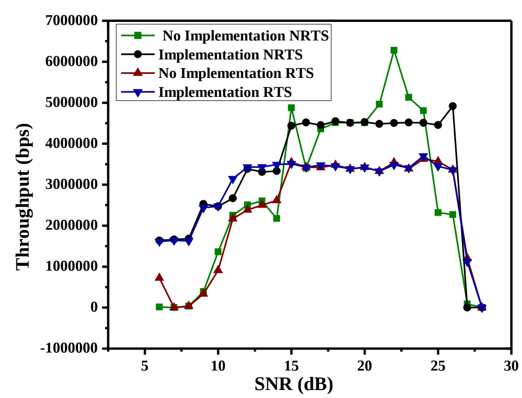

Fig.7.Throughput performance of RTS and NRTS

5.1.2 SS moving towards BS

If a SS moves towards BS (Fig.5), again the moving node comes across all the channel conditions. Initially SS is far away from BS and hence the ranging and registering process with BS takes certain time. Once if the received signal strength level is adequate for data transmission, SS starts its communication with BS.

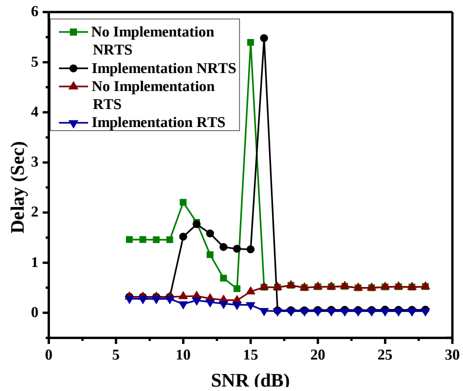

Fig.8.Delay performance of RTS and NRTS services

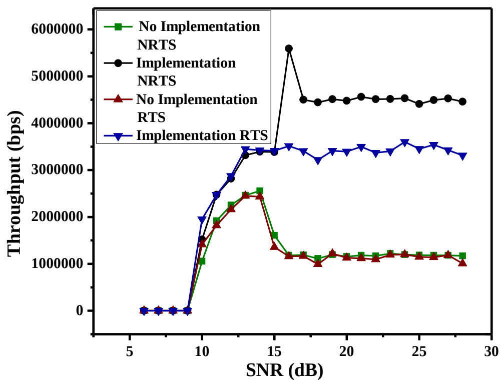

Fig.9.Throughput performance of RTS and NRTS

Fig.8 and Fig.9 depicts the delay and throughput behavior of RTS and NRTS, for both implemented work and without any implementation. When SS reaches intermediate channel condition; delay of NRTS increases, since the prioritization of RTS over NRTS. As it moves towards good channel condition delay comes down. It can be noticed that delay and throughput performances are improved for implemented work.

5.2. Scenario 2

This simulation scenario mainly aims to test the uplink load sustained by the implemented scheduler. For this the simulation design of scenario 1 is continued, but only the SS moving away from BS condition is considered. The aggregate uplink traffic load is increased in each simulation; to render this all the service types uplink traffic loads are correspondingly increased to obtain the desired traffic load.

The outcome of this simulation explains delay performance of RTS with respect to load variation (Fig. 10), considering the delay performance as trivial for NRTS. Throughput performances of RTS and NRTS services are also plotted for varying traffic load (Fig. 11). Delay and throughput performances depicted by Fig.10 and Fig.11 reveal that certainly the implemented scheduler can withstand a high load. It is observed that with the increase in data rate delay (Fig.10) also increases, for the implemented work delay curve has certain dips. This is due to the queue length based behavior of the proposed algorithm, in the meantime it is noticed that the delay variation is bounded and performance is better compared to no implementation. Throughput performance (Fig.11) reveals that the implemented scheduler enhances the performance compared to no implementation, but NRTS throughput comes down after a certain data rate.

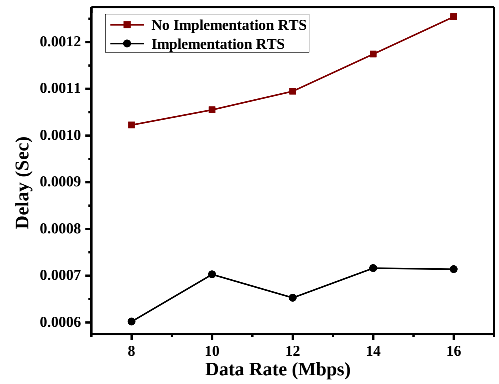

Fig.10.Dealy performance of RTS services

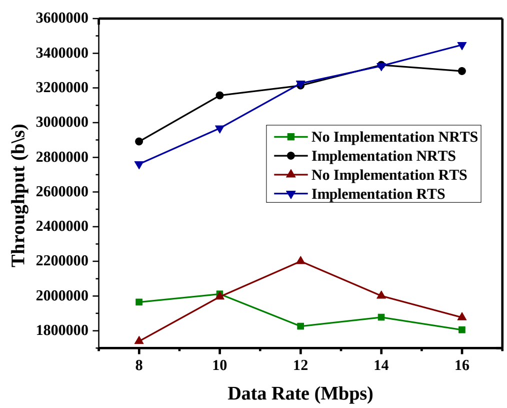

Fig.11.Throughput performance of RTS and NRTS

5.3 Scenario 3

This scenario is designed to verify the results of implemented work for all the MCS levels. It retains all settings of scenario 1 except the moving node becomes stationary in this scenario. The static node transmitting all the uplink traffics is placed at a suitable distance from BS to confirm a particular MCS and simulation is performed.

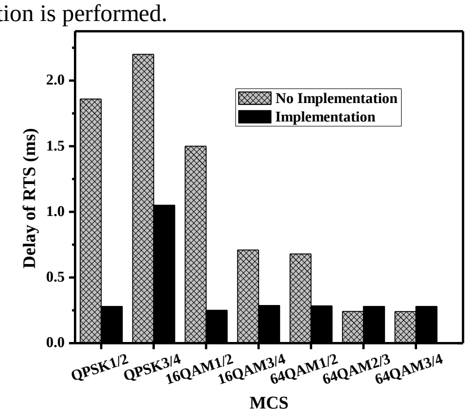

Fig.12.Delay performance of RTS

In this way multiple simulations are conducted to cover all the MCSs. Fig.12 and Fig.13 depict the delay and throughput performance of RTS. Fig.14 gives the throughput behavior of NRTS. The impact of channel categorization on scheduling can be observed by these results. Implemented scheduler outperforms no implementation results for all MCS. The delay and throughput performances are prominent for implemented work, particularly it is notable for QPSK ½ to 64QAM ½ MCS. For 64QAM 3/4 and 64QAM 2/3, because of good data rate and signal conditions, all the performance metrics related to implemented work trace the no implantation results.

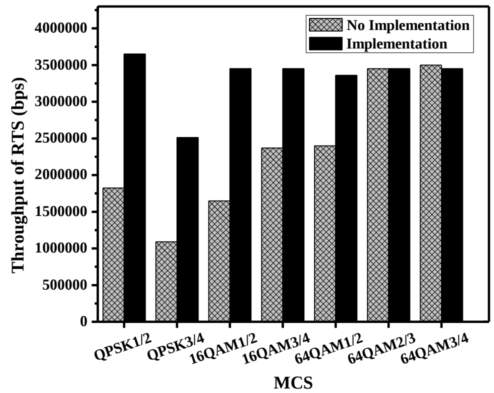

Fig.13.Throughput performance of RTS

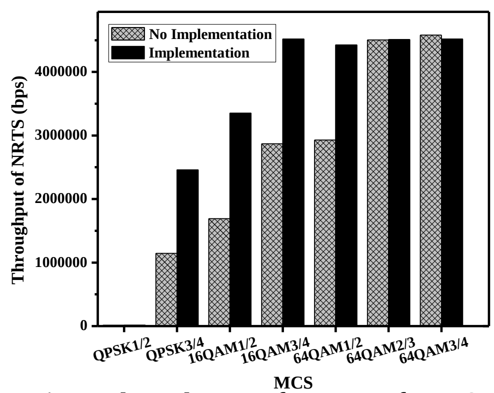

Fig.14.Throughput performance of NRTS

5.4 Scenario 4

In this scenario the total system performance is evaluated by increasing the system load, here the scenario 3 is retained.

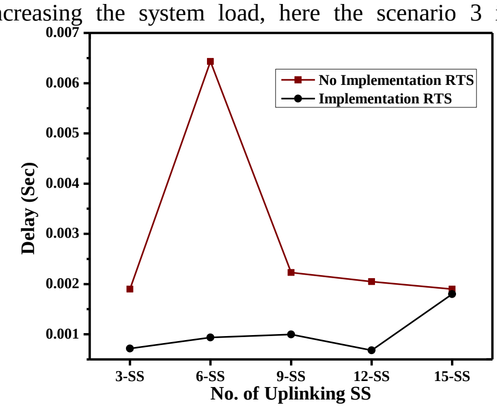

Fig.15. Delay performance of RTS services

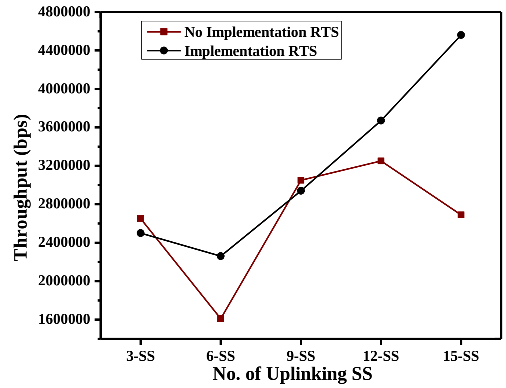

Fig.16.Throughput performance of RTS service

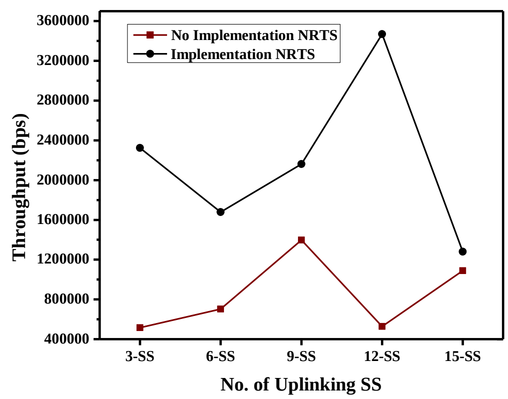

Fig.17.Throughput performance of NRTS services

Initially this scenario consists of three SSs each one carrying the uplink traffic placed at QPSK, 16QAM and 64QAM regions. In next simulation scenarios this number goes on increasing in order six, nine, twelve and fifteen (corresponding to MCSs QPSK, 16QAM and 64QAM SS are increased by one). Delay and throughput results compare the implemented work with no implementation for RTS and NRTS. Fig.15 and Fig.16 show delay and throughput performances of RTS; it is observed that implemented scheduler performs better when the system load varies. In the same manner Fig.17 depicts the throughput performance of NRTS, the throughput performance is better for implemented work compared to no implementation.

6. CONCLUSION

In this work, a channel aware distributed SS uplink scheduler for WiMAX is proposed and implemented using QualNet 5.0.2. The performance of the work was examined thoroughly by conducting simulations for different conditions. Major performance metrics of interest in this study are delay and throughput. The proposed work adopts a technique to maintain equilibrium between these QoS specifications and hence enhances overall system performance. Channel status aware, queue length variation based bandwidth reallocation has an impact on the performance of RTS and NRTS. It is observed and confirmed that scheduling intelligence at SS can substantially improve the system performance.

7. ACKNOWLEDGMENTS
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