A Channel-Aware Uplink Scheduling Algorithm for Mobile WiMAX Networks

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***Abstract*- There has been a rapid growth of new Internet services, such as video conferences, online video games, and multimedia applications, offered to end users. These services need to satisfy their quality requirements, and thus an efficient scheduling algorithm is needed. In the literature, the interest is focused on throughput and delay as inputs to the scheduler in its bandwidth allocation decision. Jitter, though of great significance, did not receive considerable attention, yet. Researchers, in the area of WiMAX networks, often recommend weighted scheduling algorithms with dynamic weight functions. The channel quality is particularly important as well in scheduler decision in wireless networks for the determination of channel strength. In this paper, we develop an uplink channel-aware scheduling algorithm for mobile WiMAX networks. Use is made of a weight function with four terms: throughput, delay, jitter, and channel quality. A comparison is made between the proposed algorithm and two famous channel-aware algorithms, namely, proportional fair scheme (PFS) and maximum carrier-to-interference ratio (Max C/I). Simulation results, obtained by an OPNET simulator, reveal that our algorithm outperforms both PFS and Max C/I with respect to WiMAX delay and jitter, as functions of the number of mobile stations. However, the WiMAX throughput takes on a slightly lower value. For real-time applications, the algorithm is applied to a video conference and high quality video applications, and better values for both delay and jitter are attained in both application types.**

Keywords: WiMAX Networks; IEEE 802.16e; channel-aware algorithms; scheduling schemes; QoS

I. INTRODUCTION

Worldwide interoperability for microwave access (WiMAX) [1] is one of the emerging broadband wireless access networks. It is designed according to IEEE 802.16 standard [2]. The rapid growth of new services, such as online video games, video conferences, and multimedia services demands a reliable and efficient Internet access. WiMAX is an efficient solution to provide last-mile access to the Internet. It is suitable for real-time applications since WiMAX has a multitude of advantages features in this respect [1][3]; these are (1) use of orthogonal frequency division multiple access (OFDMA) in the physical layer, which allows WiMAX to operate in Non-Line of sight (NLoS) by using multiaccess scheme for broadband wireless access; (2) having a high data rate, capable of using 74Mbps on 20MHz wide spectrum; (3) supporting adaptive modulation and coding rate technology (AMC); (4) being suitable for both time division duplexing (TDD) and frequency division duplexing (FDD); (5) enjoying strong and robust security; and (6) allowing Quality of Service (QoS), which is responsible for serving different applications with dissimilar requirements.

QoS is the main feature of WiMAX networks [3][4], used to manage the available resources in such a way as to enhance the performance of the network. It has three main parameters, namely, throughput, delay, and jitter. QoS in broadband wireless access is highly important. Yet its achievement is sophisticated since the performance of the radio link channel is unpredictable. The channel status indicating parameter is the carrier-to-interface-plus-noise ratio (CINR) [1][2].

A scheduling algorithm is part of the QoS architecture. Its function is the division of bandwidth among subscriber stations (SSs) in order to maximize throughput and minimize both delay and jitter. The scheduler should be simple, fair, and efficient [3][4]. The wireless channel is influenced by many factors such as: signal attenuation, fading, interference, and noise ratio. So, it is preferred to use a scheduling algorithm which can take the channel status in its bandwidth allocation decision [1][3].

A comprehensive survey on scheduling algorithms in WiMAX networks is given in [3]. In [5], a detailed performance study of uplink scheduling algorithms in point-to-multipoint WiMAX networks is made, where simulation analysis is carried out using average delay, average throughput, fairness and frame utilization and the simulation results indicate that none of the algorithms considered is capable of effectively supporting all WiMAX classes of service. Recently, in [6], a comparative descriptive analysis for various scheduling algorithms in WiMAX networks is presented.

The work in [7] is focused on the importance of the scheduling algorithm in WiMAX networks to ensure the usefulness of delay, jitter and throughput. Also, it explains deficit round robin (DRR) and weighted deficit round robin (WDRR), but no analysis study is given. In [8], a new packet scheduling and bandwidth allocation algorithm is developed. This scheduling algorithm is divided into two tiers. In tier 1, four queues are used by the service classes and each service class uses an intra-class scheduling algorithm to decide which packet will be served. In tier 2, the chosen packets are arranged in a matrix and an inter-class scheduling algorithm is used to move packets to the frame. Two inter-class scheduling algorithms, dynamically allocating priority queue (DAPQ) and dynamically allocating weighted fair queue

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(DAWFQ) are used. A simulation analysis using OPNET is presented. A new strategy about scheduling algorithms based on intelligent systems is suggested in [9]. The suggested algorithm is based on fuzzy systems and neural networks. This algorithm is divided into two stages: Priority stage using fuzzy systems and the allocation of bandwidth stage using neural networks. A performance comparison between the suggested algorithm and some scheduling algorithms are presented using OPNET and Matlab. All these algorithms belong to the channel-unaware category.

Weighted scheduling algorithms are preferred for the satisfaction of QoS requirements [10]. The reason is that the weight corresponds to the number of time slots to be allocated to the service class. This number of slots is fixed for each WiMAX frame; hence the weight representing the number of slots is preferably to be an integer. This means that we do not actually need algorithms such as DRR [7] [10], in which floating point numbers are used. Further, the resulting algorithm will be much less sophisticated. In [11], a study of the performance of four scheduling algorithms: round robin (RR), MAX CINR, fair throughput (FT), and proportional fair scheme (PFS) is presented. The results reveal that MC has the highest throughput but with lowest fairness, but the converse happens for FT scheduling. PFS has the ability of adjusting the throughput and fairness with application requirements. In [12], three channel-aware scheduling algorithms in mobile WiMAX networks: PFS, modified longest weighted delay first (MLEDF), and exponential rule are studied and compared with a suggested algorithm using a queue length and waiting time of the packet in a weight equation. The results indicate that the suggested algorithm outperforms the other algorithms in throughput and delay.

It is known that channel-aware schedulers are more suitable than channel-unaware schedulers in ensuring QoS requirements for wireless networks [1][3]. Also, the weighted scheduling algorithms are preferred to use in WiMAX networks [10]. The present paper develops a channel-aware uplink scheduling algorithm for mobile WiMAX networks. Its bandwidth allocation decision is taken based on throughput, delay, jitter, and channel quality. The proposed algorithm is compared with PFS, and MAX CINR with performance metrics: WiMAX throughput, delay, jitter, real-time application delay, and real-time application jitter. The results reveal that the proposed algorithm outperforms the other algorithms, with respect to WiMAX delay, and jitter as functions of the number of mobile stations, but the proposed algorithm gives a lower throughput than both algorithms PFS and Max C/I. Results of the proposed algorithm demonstrate that delay and jitter in real-time applications evidence that our algorithm transcends the other algorithms.

The rest of this paper is organized as follows. In Section II, an overview of WiMAX networks is given. Scheduling algorithms are reviewed in Section III. Section IV presents the details of the proposed approach. Simulation results are introduced in Section V. Finally, conclusions and trends for future work are reported in Section VI.

II. WIMAX FRAMEWORK

WiMAX is the most efficient technique of broadband wireless access networks [1][3]. It is used as a last-mile network to introduce the Internet for end users in an efficient and reliable way. WiMAX networks based on IEEE 802.16 standard are divided into two main layers: the physical layer (PHY) and the medium access control layer (MAC).

The PHY layer is defined on IEEE 802.16 standard [2] using four physical layer types: wireless MAN-OFDM (orthogonal frequency division multiplexing), wireless MAN-SC (single carrier), wireless MAN-SCa, and wireless MAN-OFDMA (orthogonal frequency division multiple access).

WiMAX uses two types of duplexing [1][2][3]: frequency division duplexing (FDD) and time division duplexing (TDD) in the frame structure. In our work, we use TDD. In TDD, the frame structure consists of two subframes: downlink subframe and uplink subframe. Downlink subframe sends data from the base station (BS) to subscriber stations (SSs) together with some control information such as: preamble, downlink and uplink maps. Uplink subframe implies uplink bursts in addition to control information, such as channel quality information, which is sent from SSs to BS. Downlink and uplink subframes are separated by a transmit-receive transition gap (TTG) and a receive-transmit transition gap (RTG).

The MAC layer [1][3][4] is the intermediate layer between the PHY layer and higher layers. It is responsible for many important jobs such as header suppression, packet scheduling, bandwidth allocation, QoS management, and security and authentication issues.

To facilitate MAC layer work, the MAC layer is divided into three sub-layers. Each sub-layer is responsible for doing some of MAC functions. The three sub-layers are: convergence sub-layer, common-part sub-layer, and security sub-layer. First, a convergence sub-layer is designed as a link between higher layers and WiMAX MAC layer. This is done by mapping data from the upper layers to the appropriate MAC layer. Second, a common part sub-layer is responsible for bandwidth allocation, connection establishment and maintenance for all QoS requirements. Third, a security sub-layer is developed for authentication, security key exchange, and encryption.

WiMAX supports two types of operation modes [5]: Point-to-multipoint (PMP) mode and mesh mode. In PMP mode, the communications between all SSs are organized and passed through the BS. But in mesh mode, the communications can be achieved directly between SSs.

WiMAX supports QoS by defining five different service classes for constant and variable bit rate applications. These service classes are [3][5]: unsolicited grant service (UGS), used to support constant data rate real-time applications such as VoIP without silence suppression; real-time polling service (rtPS), defined to support real-time applications with variable data rate such as a MPEG compressed video; extended real-time polling service (ertPS), used to support real-time applications with variable data rate such as VoIP with silence suppression; non-real-time polling service (nrtPS), defined for variable bit rate non-real-time applications; and the best effort (BE) service class, responsible for non-real-time applications with no need of any special requirements.

To ensure a good performance of WiMAX networks for the different requirements of QoS in real-time applications, a suitable bandwidth allocation algorithm is needed [3][4]. In the beginning of each WiMAX frame, the scheduling algorithm computes the allocated bandwidth for each SS to send this information in UL-MAP to SSs.

III. EARLIER SCHEDULERS

A powerful scheduling algorithm is essential in WiMAX networks to satisfy the growth of end user requirements for different applications [4]. There is no specific scheduling algorithm stated in IEEE 802.16 standard to use. The selection of the algorithm is left for service providers to pick a suitable one, which satisfies network application requirements.

Scheduling algorithms are classified into two main classes: channel-aware and channel-unaware scheduling algorithms, outlined in what follows.

A. Channel-unaware algorithms

In channel-unaware algorithms, the bandwidth allocation is done without any use of information about the channel status. These algorithms include: the round robin (RR) algorithm [3] is simple and fair in assigning one allocation for each connection in each serving cycle. The weighted round robin (WRR) [3][5][6] assigns a weight to each connection; then the connections are served according to their weights. The main problem of WRR is that it provides incorrect percentage of bandwidth allocation when the traffic has a variable packet size. The deficit round robin (DRR) [7][10] solves this problem of WRR. DRR defines two variables for each queue, deficit counter (DC) and quantum (Q). Q is set to a constant value equal to the maximum traffic packet of the queue, and DC is initialized by a zero value when the queue is created. When the queue is visited to serve, the value of Q is added to DC and the queue is still served until the head packet size is greater than DC. For each packet served, the value of DC decreases by the value of packet size. When the queue is empty, DC returns to zero. The deficit weighted round robin (DWRR) [13] is the same as DRR; it adds a weight variable for each queue and the Q value depends on the weight value. Another modification on DRR, named modified deficit round robin (MDRR) [13], works in the same way as DRR but a queue priority parameter is added to each queue to contribute to queue selection.

B. Channel-aware algorithms

These algorithms use channel state information from the channel quality indicator (CQI) to make the bandwidth allocation decision. Channel-aware algorithms include modified largest weighted delay first (MLWDF), proportional fairness schema (PFS), and maximum carrier to interference ratio (MAX C/I). MLWDF [14] is one of QoS-guaranteed algorithms which support minimum throughput and minimum delay. In this algorithm, for each queue j the scheduler computes a function "$\rho_i * W_j(t) * r_j(t)$", where ρ_i is a constant which should take a different value for each service class, Wj(t) can be either the delay of the head of line packet or the queue length, and $r_j(t)$ is the channel capacity for traffic i. The queue selection occurs on the basis of the function value starting from the largest value. There are many modifications of MLWDF. PFS [15] belongs to a fairness scheduler family which works based on maximizing the long-term fairness. PFS uses a ratio of channel capacity $W_i(t)$ to the long-term throughput $R_i(t)$ to select the queue which will be served. The queue selection occurs based on the ratio value starting from the largest value. The main disadvantage of PFS is that delay is not taken into account when defining the weight function. MAX C/I [11] is used to maximize the throughput. In MAX C/I, the queue is selected based on the best channel conditions. In WiMAX, the most used channel quality indicator is CINR. This algorithm checks the value of CINR for each queue and the queue with the largest CINR is served first. The movement between the queues occurs based on the CINR value in descending order.

All the above-mentioned scheduling algorithms, channel-aware and channel-unaware, have the following drawbacks. In weighted scheduling algorithms, the bandwidths are assigned statically and do not vary with the burst changes; no enough attention is given to jitter, causing problems in real-time applications; priority scheduling algorithms caused starvation in low priority classes; and finally, the use of channel-aware scheduling algorithms are preferred because of the nature of wireless communications . According to [3], and to the best of our knowledge, no channel-aware scheduling algorithms using jitter delay in its weight function are available in the literature.

IV. THE PROPOSED ALGORITHM

In WiMAX networks, the BS is responsible for scheduling service classes in both uplink and downlink directions. Any scheduling algorithm works on the basis of the bandwidth requests of SSs in the uplink direction [2][3][4].

The proposed approach is a type of channel-aware weighted scheduling algorithms with a weight equation defined in terms of: throughput, delay, jitter, and channel quality. These parameters characterize the QoS and the wireless communication of the application at hand.

For each type of applications, the importance of these parameters is varying. In real-time applications which belong to rtPS service class in WiMAX, the QoS parameters are all important and none of them can be dispensed with. But, in non-real-time applications, which belong to nrtPS class in WiMAX, throughput is the only important parameter, since non-real-time applications are insensitive to delay and jitter. The channel quality is important to be considered for both real- and non-real- time applications.

The problem under consideration is concerned with the development of a dynamic uplink scheduling algorithm for mobile WiMAX networks. The bandwidth is to be allocated among n queues; that is, n subscriber stations. The proposed method depends on the formulation of a weight function in terms of the parameters: throughput, delay, jitter, and channel quality. To this end, a weight $W_i(t)$ is assigned to queue i as a positive factor of the form:

$$W_i(t) = \frac{S_i(t)}{\sum_{j=1}^{n} S_j(t)} \qquad 1 \le i \le n \tag{1}$$

In (2), $S_i(t)$ is expressed as the sum of four terms corresponding to contributions of throughput, delay, jitter, and channel quality, respectively. Specifically, we propose the following formula for a weight function $S_i(t)$:

$$S_i(t) = TH_i + Dly_i(t) + JTR_i(t) + CH_i(t) \tag{2}$$

The first term TH_i, in (3), is the fractional throughput contribution to $S_i(t)$, defined as:

$$TH_i = \frac{X_i}{\sum_{j=1}^{n} X_j} \quad (3)$$

where X_i is the minimum reserved traffic rate for queue i. The second term $Dly_i(t)$ is the fractional delay contribution

$$Dly_i(t) = \frac{\alpha_i Y_i(t) / L_i}{\sum_{j=1}^{n} \alpha_j Y_j(t) / L_j} \quad (4)$$

where $Y_i(t)$ is a time-varying average delay, L_i is the given maximum latency, and αi is a positive delay weighting factor. In (4), the ratio $Y_i(t)/L_i$ (less than unity) expresses the proportion of the delay of a particular queue relative to the maximum acceptable delay of the network. Further, the ratio $Y_i(t)/L_i$ is weighted by a factor αi, whose value varies according to the subscriber station (value of i). This is justifiable since each subscriber station is devoted to a particular application. The third term $JTR_i(t)$ is the fractional jitter contribution,

$$JTR_i(t) = \frac{\beta_i Z_i(t) / K_i}{\sum_{j=1}^{n} \beta_j Z_j(t) / K_j} \quad (5)$$

where $Z_i(t)$is a time-varying average jitter, K_i is the given maximum jitter and β_i is a positive jitter weighting factor. The terms in (5) can be interpreted in the same way as in (4). The fourth term $CH_i(t)$is the fraction channel quality indicator

$$CH_i(t) = \Omega_i * \frac{CINR_i(t)}{\sum_{j=1}^{n} CINR_j(t)} \quad (6)$$

where $CH_i(t)$is the carrier-to-interface-plus-noise ratio of the channel between BS and the MS, **Ω**i is the CINR status which indicates that CINR increases or decreases. **Ω**i takes on a value of +1 when CINR increases and the value -1 when CINR decreases. Then the bandwidth is divided among the n queues using the form given in (7):

$$BW_i(t) = W_i(t) * UL_{BW} \quad (7)$$

where $BW_i(t)$ is the bandwidth reserved to queue i and UL_{BW} is the total bandwidth of the uplink subframe.

Equation 2 is valid for both real- and non-real time applications; this implies that the weighting factors α_i and β_i should take on different values of the two types of applications. The values of α_i and β_i for real-time applications should be greater than those for non-real-time applications. The reason is the fact that real-time applications are more sensitive to delay and jitter. The criterion for the choice of the values of α_i and β_i depends on a developed algorithm which is introduced in [16] on the basis of the importance of delay for real- and non-real-time applications. We use the ratio 1:10 for α_i to β_i .

The computational scheme of the proposed algorithm is itemized in the following consecutive steps:

1) For each queue, get the values of $Y_i(t)$ and $Z_i(t)$.
2) Calculate the values of TH_i (in (3)), DLY_i (in (4)), JTR_i (in (5)), and $CH_i(t)$ (in (6)).
3) Calculate the four-term weight function $S_i(t)$ according to (2).
4) Calculate the weight $W_i(t)$ by virtue of (1)
5) Divide the bandwidth of the uplink subframe among the n queues based on (7).
6) The value of the bandwidth of each queue is sent to MS.
7) The service for the queue is continued until the assigned division of the bandwidth is used up.
8) The service is moved between the queues using round robin mechanism.

V. EXPERIMENTAL SCENARIOS AND SIMULATION ANALYSIS

The network used consists of four WiMAX service classes: ertPS, rtPS, nrtPS and BE with applications: VoIP, video conference, FTP and HTTP, respectively. The traffic parameters for each service class are taken as those used in [5], listed in table I. Simulation in this paper is performed by the OPNET simulator [17].

TABLE I. TRAFFIC PARAMETERS

Service class	*Minimum reserved traffic rate in bps*	*Maximum sustained traffic rate in bps*	*Maximum latency in msec*	*Maximum jitter in msec*
ertPS	25000	64000	20	150
rtPS	64000	500000	30	160
nrtPS	45000	500000	100	300
BE	1000	64000	N/A	N/A

The simulation results are obtained using several experimental scenarios by varying the number of mobile stations (MSs). Each scenario consists of one BS serving a number of MSs in PMP mode of operation. The frame duration is 5 msec, with the uplink and downlink subframes having 50% of this duration each. A random topology in 1000 x 1000 m square space is used. The number of MSs varies from 6 to 36 with ratio 1:2:2:1 MSs for service classes ERTPS:RTPS:NRTPS:BE, respectively. The proposed weighted scheduling algorithm is compared with PFS and Max C/I. The WiMAX throughput, delay, jitter, real-time application delay, and real-time application jitter are considered as performance metrics. Simulation time is 10 minutes.

The results of the overall WiMAX throughput, delay, and jitter are shown in Figures 1, 2, and 3, respectively. The performance of the real time applications delay and jitter are shown in Figures 4, 5, 6, and 7, respectively.

As shown in Figure 1, the proposed algorithm has a lower throughput than PFS and Max C/I, and a higher throughput varying between PFS and MAX C/I. As mentioned in [14][15], PFS and Max C/I are designed to maximize throughput with no delay guarantee in PFS, but Max C/I supports delay minimization.

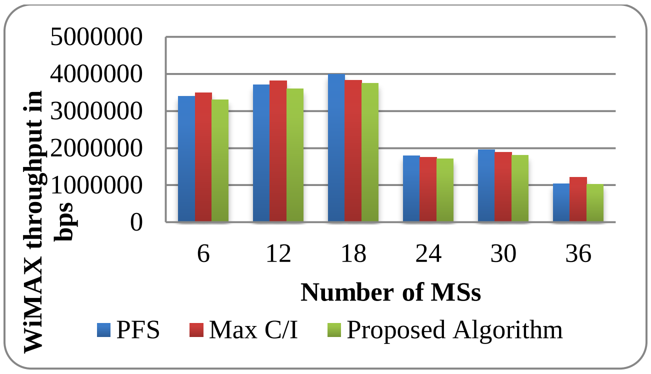

Figure 1: Average WiMAX Throughput in bps *vs.* number of mobile stations

As shown in Figure 2, it is clear that the proposed algorithm has a lower delay than PFS and MAX C/I for increasing the number of SSs. PFS has a higher delay since it does not support any delay guarantee [14]. Max C/I has a delay less than PFS since Max C/I supports delay minimization [15].

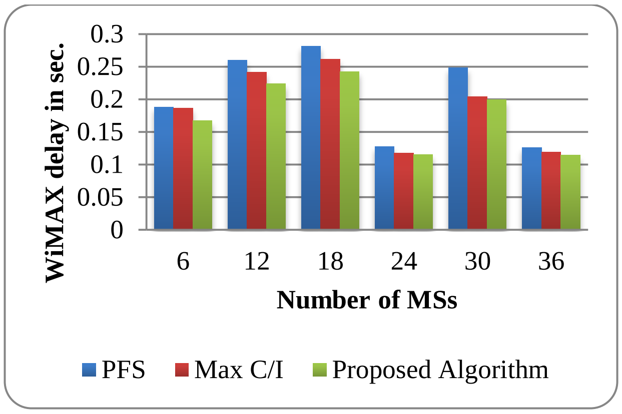

Figure 2: Average WiMAX delay in sec. vs. number of mobile stations

From Figure 3, we can conclude that the proposed algorithm has a lower jitter than PFS and MAX C/I for increasing the number of SSs.

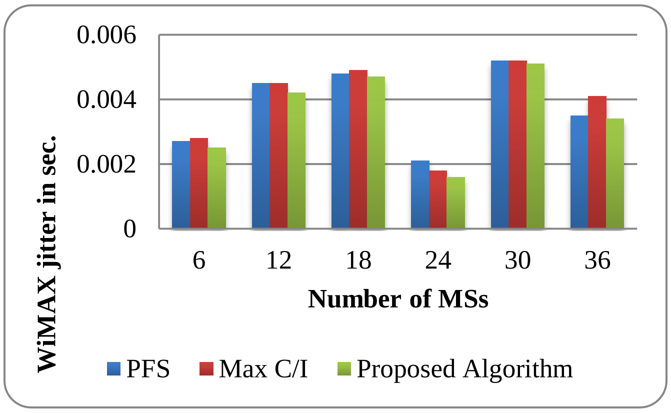

Figure 3: Average WiMAX jitter in sec. vs. number of mobile stations

In Figure 4, the results of the video conference delay are presented, and we can see that the proposed algorithm presents the best video conference delay value when the number of MSs changed.

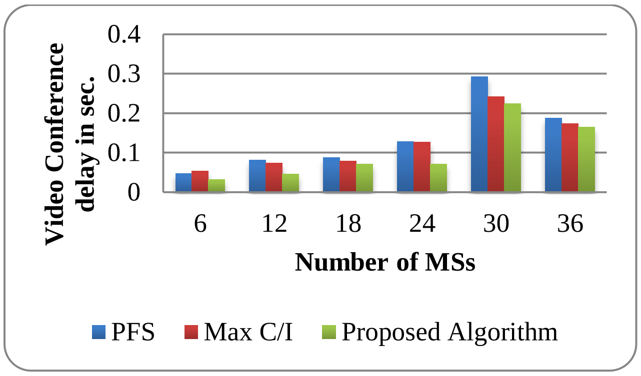

Figure 4: Video Conference delay in sec. *vs.* number of mobile stations

In Figure 5, the results of the video conference jitter are displayed, and we can see that the proposed algorithm has a lowest jitter value than PFS and Max C/I when the number of MSs changed.

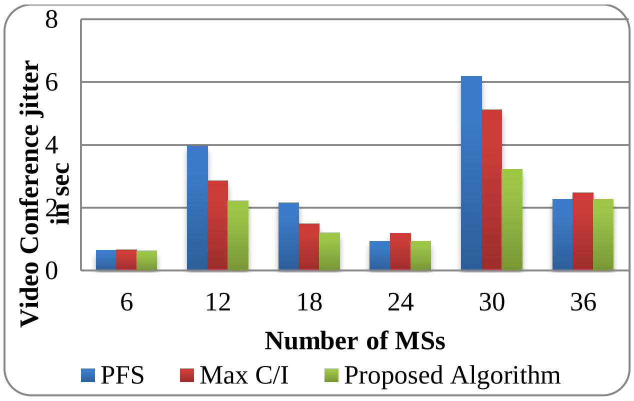

Figure 5: Video Conference jitter in sec. vs. number of mobile stations

High quality video performance delay and jitter are shown in Figures 6 and 7. From Figures, we conclude that the proposed algorithm has better values for both delay and jitter than the others algorithms.

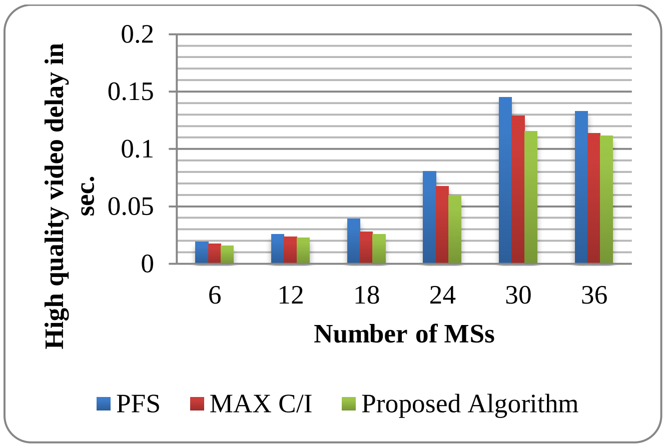

Figure 6: High Quality Video delay in sec. vs. number of mobile stations

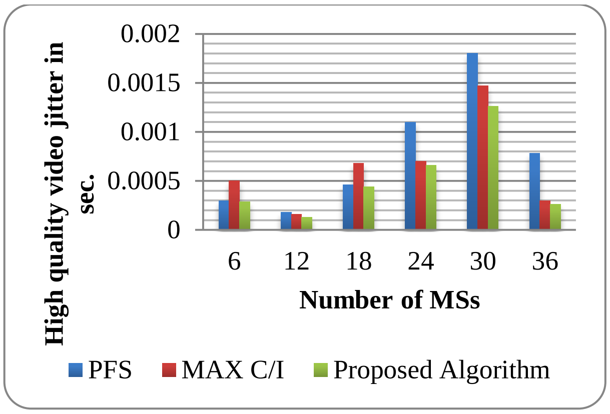

Figure 7: High Quality Video jitter in sec. *vs.* number of mobile stations

The best performance of our algorithm is caused by the using of delay and jitter contribution terms in the weight function with high importance for real-time applications. But the other algorithms (PFS and MAX C/I weight functions focused on the throughput contribution only.

VI. CONCLUSIONS

An uplink channel-aware weighted scheduling algorithm for mobile WiMAX networks has been proposed. This algorithm has advantages: it is weighted scheduling algorithm with the use of jitter and channel quality as parameters in its weight function. A comparison is made with two powerful algorithms: PFS and Max C/I. The proposed algorithm is simulated using OPNET.

The results demonstrate that the proposed algorithm outperforms the other algorithms with respect to WiMAX delay, and jitter as functions of the number of mobile stations; also, the proposed algorithm gives a lower throughput and higher load than both algorithms PFS and Max C/I. The algorithm is applied to a video conference and high quality video applications. The results of the real-time applications delay and jitter show that our algorithm transcends the others. The performance evaluation of the proposed algorithm in Long-Term Evolution (LTE) networks [18] will be considered as a future work.

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