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## **QoS requirements for bandwidth request and allocation in WiMAX Networks**

**Abstract.** Quality of Service (QoS) is the ability of a network to provide a service at an assured service level. The availability of different classes of scheduling services in WiMAX enables multiple services and applications. This is a key advantage of WiMAX (and 4G technologies) over current 3G wireless technologies. The subject of contention slot allocation is still an open research area in WiMAX networks since the WiMAX specifications leaves that open for network operators to define their own contention slot and bandwidth request allocation algorithm to promote design differences. This article presents a mathematical model for access delay estimation. The access delay for the WiMAX network is calculated on a per frame basis. The algorithm for average access delay is used to estimate the average delay on the network by varying the number of subscriber station; contention slots and probability of transmission. This algorithm will help network operators of WiMAX to be able to estimate whether the delay on the network can guarantee the QoS needed for the service flows.

**Keywords:** WiMAX; bandwidth request; contention slot; access delay; quality of service; scheduling algorithm; subscriber station.

## INTRODUCTION

Quality of Service (QoS) is the ability of a network to provide a service at an assured service level. QoS encompasses all functions; mechanisms and procedures in the cellular network and terminal equipment's that ensures the provision of the negotiated service quality between the subscriber station and the core network (CN) [1]. To enable a wide variety of data services and applications; Worldwide Interoperability for Microwave Access (WiMAX) is equipped with a number of mechanisms to ensure QoS over the wireless interface. The Medium Access Control layer (MAC) is primarily responsible for ensuring QoS over the wireless interface. As a broadband wireless access network; WiMAX is designed to accommodate different types of services such as voice; video and data. Each of these services has its own requirements in terms of performance. These performance metrics can be summarized into the following four parameters:

- Throughput: indicates the requirements of the services in terms of bandwidth measures in bits/second.
- Latency: indicates the delay time for the information to travel from source to destination.
- Jitter: indicates the variations in latency.
- Loss: indicates the percentage of packet loss the service can tolerate.

### A. Connections and Service Flows

The WiMAX medium access control (MAC) is connection-based where all services and traffic (even connection-less traffic) are mapped to a connection. Each logical connection between the peer MAC layer of the base station (BS) and the subscriber station(SS) is identified by a 16-bit unidirectional identifier (Connection Identifier -CID) which is used to identify all information exchanged between the base station and subscriber station after the initial registration and authentication. Another important concept of the WiMAX MAC is that of a service flow; which defines a connection through a set of QoS parameters. A 32-bit service flow identifier (SFID) is mapped to a unique CID and the base station maintains the association between the two identifiers. Multiple service flows per subscriber station are possible. A scheduling service is used to determine the mechanism to allocate transmission opportunity for MAC packet data units (PDUs). Mobile WiMAX defines five scheduling services as summarized in Table 1.

**TABLE 1**

### SCHEDULING SERVICES IN MOBILE WIMAX

	Applications	Mandatory QoS Parameters
<b>UGS</b> Unsolicited Grant Service	El/TI; VoIP (without silence suppression)	<ul style="list-style-type: none"> <li>• Maximum Sustained Traffic Rate (= minimum reserved traffic rate)</li> <li>• Maximum Latency Tolerance</li> <li>• Jitter Tolerance</li> </ul>
<b>rtPS</b> Real-Time Packet Service	Streaming Audio or Video (e.g. MPEG)	<ul style="list-style-type: none"> <li>• Minimum Reserved Traffic Rate</li> <li>• Maximum Sustained Traffic Rate</li> <li>• Maximum Latency Tolerance</li> <li>• Traffic Priority</li> </ul>
<b>ertPS</b> Extended Real- Time Packet Service	Voice with Activity Detection (VoIP)	<ul style="list-style-type: none"> <li>• Minimum Reserved Traffic Rate</li> <li>• Maximum Sustained Traffic Rate</li> <li>• Maximum Latency Tolerance</li> <li>• Jitter Tolerance</li> <li>• Traffic Priority</li> </ul>

	Applications	Mandatory QoS Parameters
<b>nrtPS</b> Non-Real-Time Packet Service	File Transfer Protocol (FTP)	<ul style="list-style-type: none"> <li>• Minimum Reserved Traffic Rate</li> <li>• Maximum Sustained Traffic Rate</li> <li>• Traffic Priority</li> </ul>
<b>BE</b> Best-Effort Service	Data Transfer; Web Browsing; etc.	<ul style="list-style-type: none"> <li>• Maximum Sustained Traffic Rate</li> <li>• Traffic Priority</li> </ul>

The availability of different classes of scheduling services in WiMAX enables multiple services and applications. This is a key advantage of WiMAX (and 4G technologies) over current 3G wireless technologies. Applications can be characterized according to key requirements for throughput; delay; jitter; and information loss. Table 2 shows such classifications of applications over five different “Services Classes.” This helps in the future planning of WiMAX networks to ensure that the offered applications are properly supported.

**TABLE 2**

**APPLICATION QOS REQUIREMENTS**

Service Class	Service Class	Application Layer Throughput	End-to-End Transport Layer One Way Delay	End-to-End Transport Layer One Way Delay Variation	Transport Layer Information Loss Rate
1	Real-time Games	50-85 Kbps	< 60 ms preferred	< 30 ms preferred	<3%
2	Conversational (e.g.;VoIP and Video Phone)	4-384 Kbps	< 60 ms preferred < 200 ms limit	< 20 msec	<1%
3	Real-time Streaming(e.g.; IPTV; Video Clips and Live Music)	>384 Kbps	< 60 ms preferred	< 20 ms preferred	< 0.5%
4	Interactive Applications (e.g.; Web Browsing and Email Server Access; IM)	>384 Kbps	< 90 ms preferred	N/A	Zero
5	Non-Real-time Download (e.g.; Bulk Data; Movie Download and P2P)	>384 Kbps	< 90 ms preferred	N/A	Zero

**RELATED WORK**

Scheduling services represent the data handling mechanisms supported by the MAC scheduler for data transport on a connection. Each connection is associated with a single scheduling service. A scheduling service is determined by a set of QoS parameters that quantify aspects of its behavior. In review [2] different scheduling algorithms has been analyzed; giving an insight to where each one can be applied. In review [3] two scheduling algorithms are used to calculate the data in the MAC layer in order to improve the throughput. Among the scheduling algorithms used; priority queueing gave a better throughput result compared to random early detection while in [4] a dynamic system-level simulation platform was proposed to improve on the QoS of the system. They also propose methods of scheduling the service flows in order to decrease the dependence of the subscriber station (SS) on the BS while ensuring QOS much more effectively.

In reviews [5] [6] [7] packet loss; throughput and end-to-end delay are used to evaluate QoS on the WiMAX network. Review [6] evaluated how handoff affected these parameters and validated its results using both NS2 and Qualnet while review [5] used pre-WiMAX environment to investigate the impact of delay-jitter on fixed and mobile environment using throughput and packet loss as determining parameters.

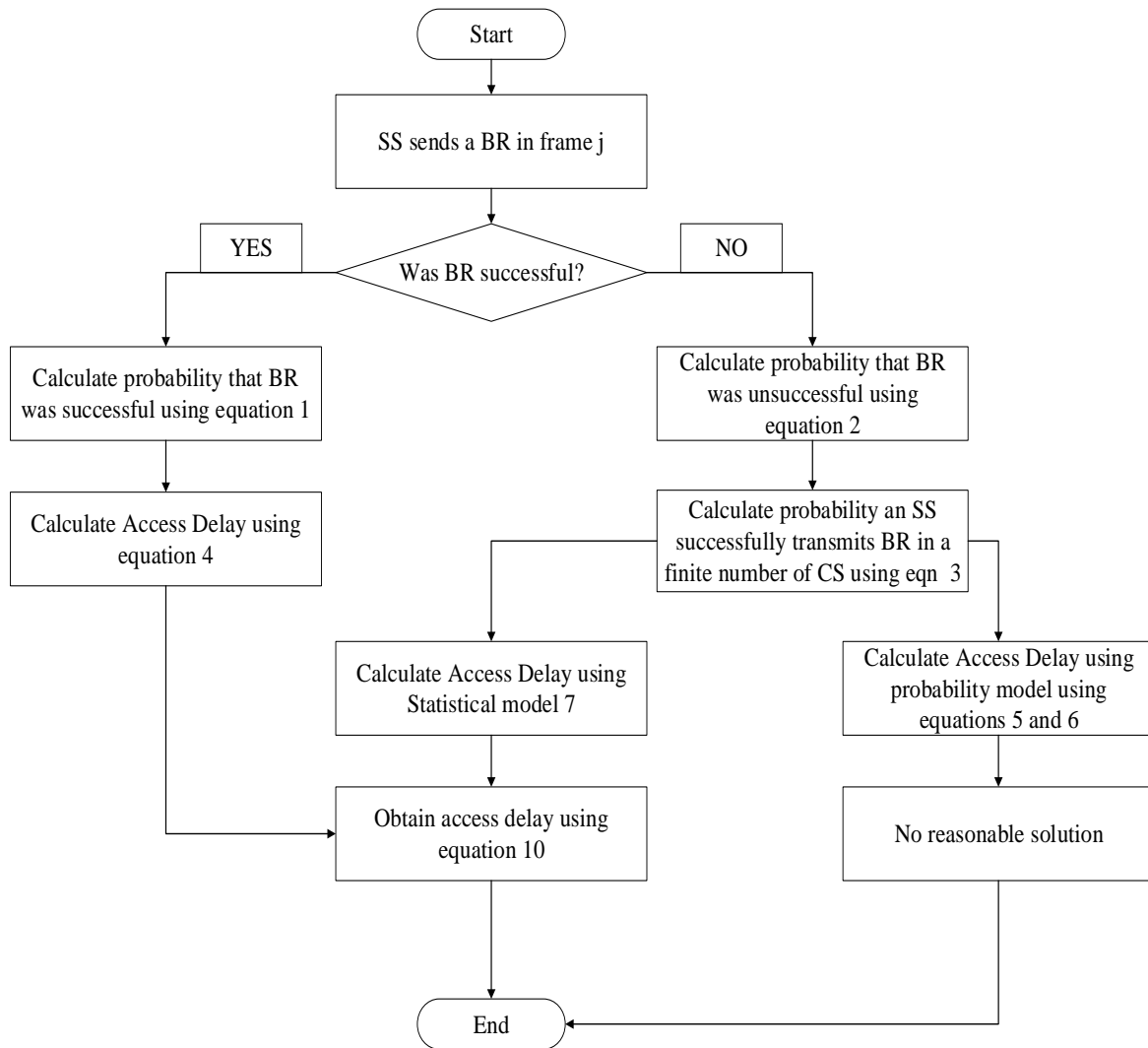
For data to be scheduled in WiMAX networks a request has to be made. Request refers to the mechanism that an SS uses to indicate to the basestation that it needs an uplink bandwidth allocation [8] it may come in the form of a stand-alone bandwidth request or as a piggyback request. The subject of contention slot allocation is still an open research area in WiMAX networks since the WiMAX specifications leaves that open for network operators to define their own contention slot and bandwidth request allocation algorithm to promote design differences. Review [9] proposes a dynamic contention slot resolution scheme for WiMAX network. It groups the requests based on their service flows and dynamically calculates the number of contention slots based on the arrival rate of the requests while review [10] calculates the time taken for a request to be granted on per frame basis system. Such model will be adapted in this work to calculate the access delay on the WiMAX network. None of the works looked at above took realistic values for WiMAX QoS parameters to calculate the access delay in the network. In this paper; we looked at realistic parameters like number of subscriber stations; probability of transmission by an SS and number of contention slots allocated in the uplink to determine whether the access delay that will be experience in the network will support the QoS demands of the service flows presented in the WiMAX standard

#### **PROPOSED ANALYTICAL MODEL**

In random multiple access networks; where the number of users may exceed available access channel resources; contention is considered a fair method to provide access to users' random transmissions. Most of the access technologies employing reservation MAC protocols do not mandate a specific number or schedule of contention slots (CS) in the uplink subframe. CSs could be scheduled in a collective or sporadic fashion along the uplink subframe.

##### *A. Flowchart description of the algorithm for access delay calculation*

Upon generation; of a bandwidth request (BR); a packet is transmitted in the beginning of the next contention frame by carrying out a Bernoulli experiment. Figure 7. Shows the flowchart of the algorithm



**Fig. 7.** Flowchart for access delay calculations

The outcome of this Bernoulli experiment can be either successful transmission with probability  $P_{suc}$  or collision with probability  $P_{unsuc}$  where:

$$P_{suc} = \binom{N}{1} * (1 - p)^{N-1} = N * p * (1 - p)^{N-1} \quad (1)$$

$$P_{unsuc} = (1 - P_{suc}) \quad (2)$$

Where:

$N$  - Number of SS.

$p$ : Probability a SS transmits a packet in the beginning of CS.

In an uplink subframe; only finite number of CSs are available. Increasing the contention period in a frame increases the chance of a successful transmission during that frame. However; because the uplink subframe size is fixed; this would decrease the data slots (DS) period and hence decrease the system's throughput in the subject frame.  $P_{acc}(n)$  is defined as the probability that an SS successfully accesses the media in a finite number  $n$  of CS's.  $P_{acc}(n)$  implies the probability that an SS successfully transmits  $BR_i$  in that frame and can be formulated mathematically as;

$$P_{Acc}(n) = \sum_{k=1}^n P_{Acc}(k) = \sum_{k=1}^n (1 - P_{suc})^{k-1} * P_{suc}$$

$$P_{Acc}(n) = 1 - (1 - P_{suc})^n \quad (3)$$

The definition for the access delay suffered by a BR is the time from the request's first transmission until the time of its successful transmission. Since contention periods are interleaved with data slots (DS) periods; the model of access delay comprises both CS periods and DS periods. If  $BR_i$  was successfully transmitted in one of  $n_j$  CS's (in frame  $j$ ); then the expected access delay suffered would be

$$\overline{D}_{F_j} = \frac{n_j}{2} * T_{CS} \quad (4)$$

Where  $T_{CS}$ : CS duration

On the otherhand if a BR was not successful in a frame  $j$ ; the SS will request for a BR in the frame  $j+1$  and contend with  $n+1$  contention slots. The access delay in this second attempt can be formulated as follows:

$$D_{acc2} = P_{Acc} * \overline{D}_{F_j} + P'_{Acc}(n_j) * \{P_{Acc}(n_{j+1}) * (T_{ULframe} + D_{F_{j+1}})\} \quad (5)$$

If BR is not successful in the second attempt; the SS will again send a BR in the frame  $j+2$  and contend with  $n+2$  contention slots. The access delay for this attempt can be formulated as follows:

$$D_{acc2} = P_{Acc} * \overline{D}_{F_j} + P'_{Acc}(n_j) * \{P_{Acc}(n_{j+1}) * (T_{ULframe} + D_{F_{j+1}}) + P'_{Acc}(n_{j+1}) * \{P_{Acc}(n_{j+2}) * (2 * T_{ULframe} + D_{F_{j+2}}) + \}\} \quad (6)$$

This cycle will continue until the number of attempts set by the BS and the start of BR process is exhausted i.e. if the number of attempts is set to  $2^2$  then the SS will attempt to send a BR for 4 times then discard the BR. This group of probabilistic equations does not give a closed solution; therefore a statistical approach is used to obtain the access delay. If  $BR_i$  was not successfully transmitted in frame  $j$ ; the delay experienced at the beginning of frame  $j + 1$  will equal  $T_{UL\_subframe}$ . At that point; and since contention results in a frame is independent of the contention results in previous frames; the process statistically starts over and mathematically formulated as:

$$\overline{D}_{access}^l = D_{F_j} * P_{Acc}(n_j) + [T_{UL\_subframe} + \overline{D}_{access}^l] * (1 - P_{Acc}(n_j)) \quad (7)$$

Where:

$T_{UL\_subframe}$  – Duration of uplink sub frame

$\overline{D}_{access}^l$  – Access delay

Rearranging;

$$\overline{D}_{access}^l = D_{F_j} + \frac{1 - P_{Acc}(n_j)}{P_{Acc}(n_j)} * T_{UL\_subframe} \quad (8)$$

The analytical model in above equation reveals that the higher  $P_{Acc}(n_j)$  is; the lower the second delay component resulting from resuming contention over subsequent frames. Substituting (3) and (4) into (8) to obtain  $\overline{D}_{access}^l$  as a function of  $n_j$  (number CS's in frame  $j$ ) the formula becomes;

$$\overline{D}_{access}^l = \frac{n_j}{2} * T_{CS} + \frac{(1 - P_{suc})^{n_j}}{1 - (1 - P_{suc})^{n_j}} * T_{UL\_subframe} \quad (9)$$

Substituting (1) into (6); we obtain  $\overline{D}_{access}^l$  as a function of the design parameters N (system capacity);  $n_j$  (no. of frame's CS) and p (SS transmission probability) as follows;

$$\overline{D}_{access}^l = \frac{n_j}{2} * T_{CS} + \frac{(1 - Np(1-p)^{N-1})^{n_j}}{1 - (1 - Np(1-p)^{N-1})^{n_j}} * T_{UL\_subframe} \quad (10)$$

B. Model Analysis

In order to analyze the effect of access delay on QoS using equation 7 for WiMAX networks; the following parameters were chosen to enable the model to be used for realistic resource planning in WiMAX networks. These values are tabulated in table 3

**TABLE 3**

**PARAMETERS FOR ACCESS DELAY CALCULATION**

Parameter	Value	Comment
Bandwidth	20MHz	IEEE specifies 20MHz; 25MHz or 28MHz for the IEEE 802.16 standard. But from literature 20MHz gives optimum performance
Duplexing Technique	FDD	Both FDD and TDD are supported
$T_{UL-subframe}$	1ms	IEEE specifies the maximum nominal frame duration to be 200ms but recommends it to be 1ms [8]
Number of physical Slots	4000	For the 20MHz bandwidth; it is divided into 4000 physical slot. For the purpose of this work we will assume 1physical slot = 1 contention slot
Tcs	0.25s	$\frac{T_{UL-subframe}}{\text{Number of physical Slots}}$
Number of contention slots	3000	From literature; a ratio of 3:1 between Contention Slots (CS) and Data Slots (DS) gives optimal performance. It is also observed that throughput drops to 50% at the ratio of 2:1 due to overhead of contention slots. The ratio can be improved by using a dynamic (adaptive) CS/DS ratio.
Number of Subscriber station	250	From figure 2
Permissible delay for the service flows	0.04s x 0.2s	From table 2.

**RESULTS**

In this paper, we analyzed the effective allocation of CS so that the resulting access delay would be kept within QoS delay threshold; which could be a means to establish service differentiation. A frame comprising CS's and DS's is of a fixed size; increasing CS allocation in a frame improves access delay but results in reduced DS period; which reduces system throughput. The result in fig. 1 visualizes access delay sensitivity to the change of the allocated number of CS's. It can be seen that as the number of CS increases access delay also reduces. At 270 SS the access delay becomes unbearable i.e. doesn't meet any of the delay constraints of the service classes

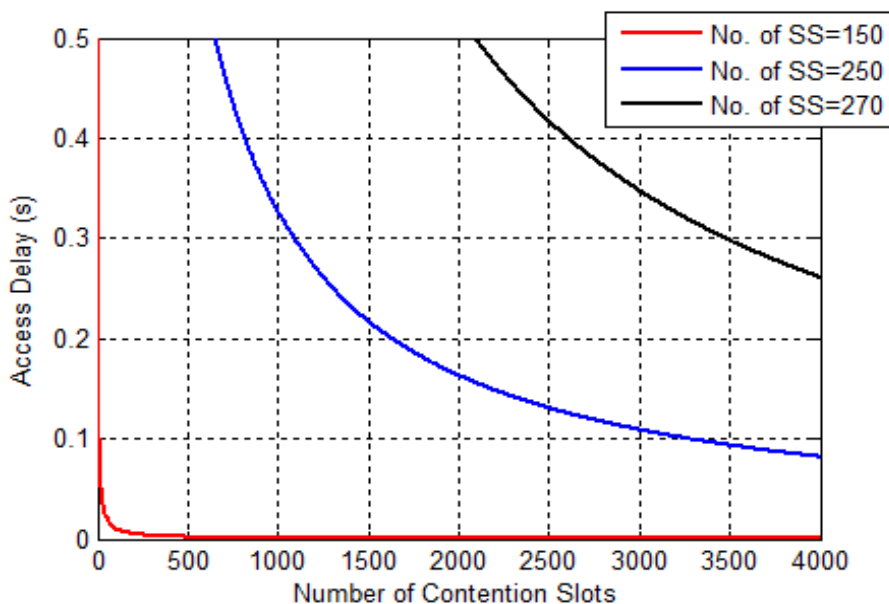


Fig 1. Effect of number of contention slots on access delay

Figure 2 shows the relation between expected access delay and number of SS's for different values of CS allocation with a fixed value of per-SS transmission probability  $p=0.06$  with the previously indicated values of  $T_{UL-subframe}$  and TCS . We observe that expected access delay remains almost unchanged with the increase of CS allocation over a range of system capacities. This renders the increase in CS allocation; in an attempt to reduce access delay; ineffective. For example in figure 2; in the range of system capacities up to 170 SS's; access delay remains approximately unchanged with the increase in CS allocation from 1000 CS's to 3000 CS's.

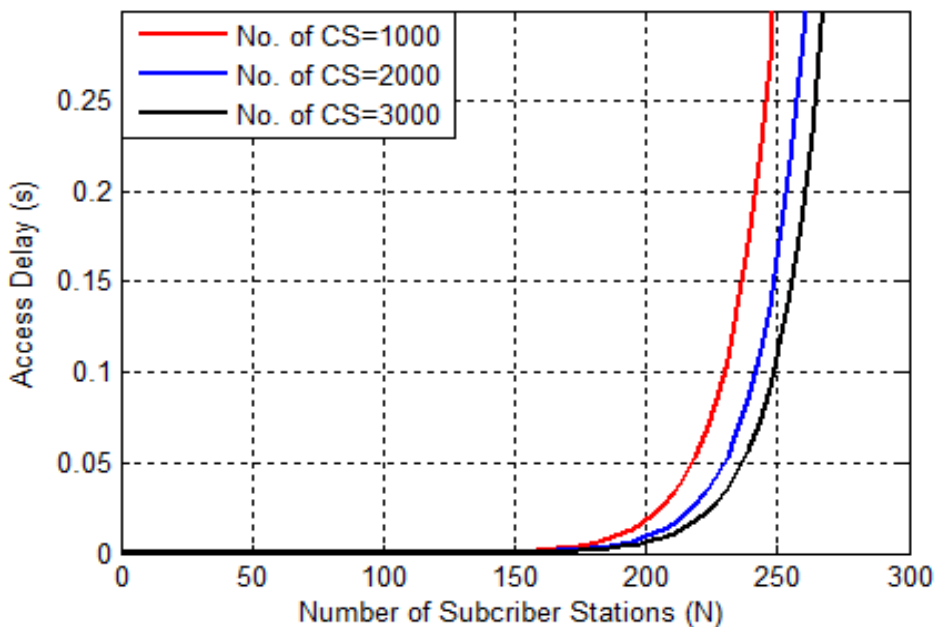
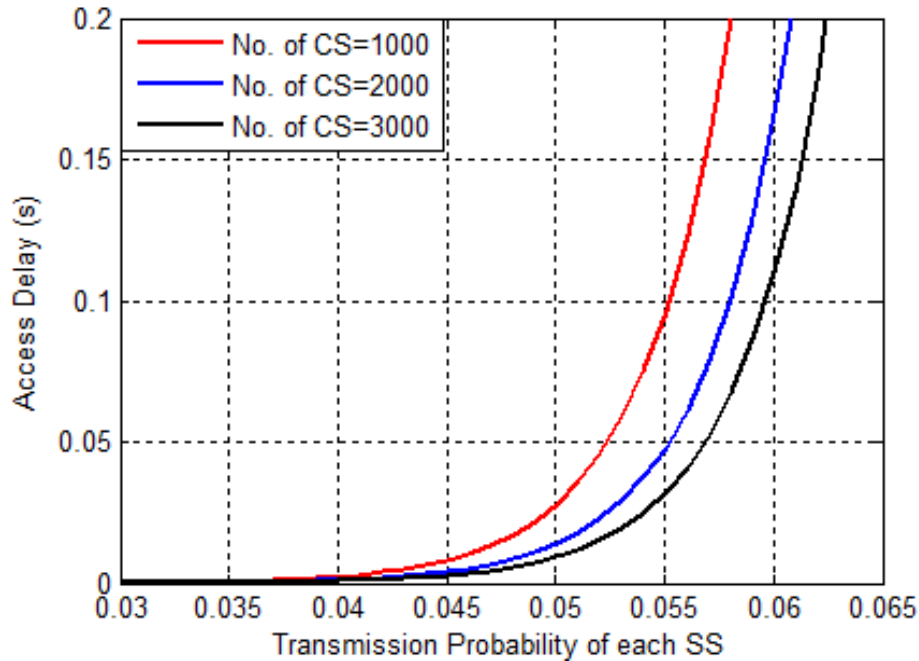


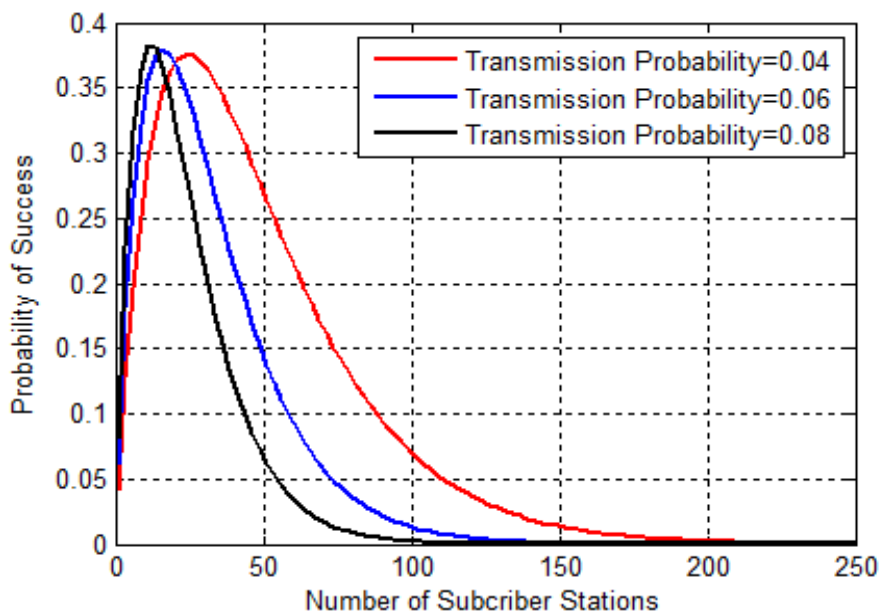
Fig 2. Effect of number of subscriber stations on access delay

Figure 3 shows the relation between expected access delay and per-SS transmission probability  $p$  for different values of CS allocation. The plots illustrate that the expected access delay is highly sensitive to slight changes in the per-SS transmission probability  $p$ .



**Fig 3.** Effect of probability of transmission on access delay

As shown in figure 3; when the transmission probability  $p$  goes beyond 0.05; the resulting expected access delay grows sharply. We observe that bringing the resulting access delay increase down will mean increasing the number of CS allocation; which will affect system’s throughput.



**Fig. 11.** Effect of number of SS on probability of transmission

At the beginning of a bandwidth request; the probability of success of a request with the least transmitting probability is the lowest fig 11. This is because the number of SS is lower (i.e. if the number of SS is 100:  $P_{0.04} = 4$  SS;  $P_{0.06} = 6$  SS;  $P_{0.08} = 8$  SS). So at the time  $t=0$ ; the probability of success with transmission probability  $P_{0.08}$  was the highest. This is because it is most possible that there will be a SS with a bandwidth request to send in CS  $n_{j_1}$  as the number of subscriber stations is the highest. As the number of SS increases the probability of success peaks at 0.3824 for  $P_{0.08}$  with 5 SS; 0.3795 for  $P_{0.06}$  with 7 SS; and 0.3753 for  $P_{0.04}$  with 10 SS. It can be noticed that all the various

transmission probabilities peaked with the actual number of SS being almost 4 with approximately equal probability of success of 0.38. In a WiMAX network; this gives an indication of how actively SS are using the network. In this article; a value of 0.06 is used; which is a fair value to describe how SS are requesting for bandwidth. This can be varied to conform to the behavior of users of any network operator.

Finally; table IV shows the relation between contention slot ( $n_j$ ) and the probability of transmission ( $p$ ) at a network load of 260 SS. This table is generated from our algorithm and gives an estimation of the access delay that will occur on the network depending on the number of contention slots ( $n_j$ ) and the probability of transmission ( $p$ ) which is a characteristic of the behavior of SS on the network. With this table; network operators can estimate access delay using these two parameters. For example at 260 SS and probability of transmission of 0.6 the optimum number of contention slots should be 3000; which gives a ratio of 3:1 for our chosen number of physical slots. However; the number of SS can also be varied to give different value for  $n_j$  and  $p$  to estimate the access delay on the network.

**TABLE 4**

**EFFECT OF NUMBER OF CONTENTION SLOT AND PROBABILITY OF TRANSMISSION ON ACCESS DELAY**

**M=260**

$n_j/p$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
<b>2000</b>	0.00025	0.00025	0.00025	0.00167	0.02238	<b>0.29198</b>	3.99749	57.5251 2	867.0285 0	13651.6978 0
<b>2200</b>	0.00028	0.00028	0.00028	0.00153	0.02035	<b>0.26544</b>	3.63409	52.2955 6	788.2077 3	12410.6343 7
<b>2400</b>	0.00030	0.00030	0.00030	0.00142	0.01866	<b>0.24333</b>	3.33125	47.9376 0	722.5237 6	11376.4148 5
<b>2600</b>	0.00033	0.00033	0.00033	0.00133	0.01723	<b>0.22462</b>	3.07501	44.2501 1	666.9450 2	10501.3060 3
<b>2800</b>	0.00035	0.00035	0.00035	0.00125	0.01602	<b>0.20859</b>	2.85538	41.0894 0	619.3061 0	9751.21274
<b>3000</b>	<b>0.00038</b>	<b>0.00038</b>	<b>0.00038</b>	<b>0.00119</b>	<b>0.01496</b>	<b>0.19470</b>	2.66504	38.3501 2	578.0190 4	9101.13191
<b>3200</b>	0.00040	0.00040	0.00040	0.00114	0.01405	0.18255	2.49849	35.9532 5	541.8928 7	8532.31119
<b>3400</b>	0.00043	0.00043	0.00043	0.00110	0.01324	0.17183	2.35154	33.8383 8	510.0168 4	8030.41055
<b>3600</b>	0.00045	0.00045	0.00045	0.00107	0.01253	0.16230	2.22092	31.9584 9	481.6825 9	7584.27665
<b>3800</b>	0.00048	0.00048	0.00048	0.00105	0.01189	0.15378	2.10405	30.2764 8	456.3309 0	7185.10421

**CONCLUSIONS**

Access delay variations is very important to service providers in a bid to meet QoS requirements for their subscribers. In this work; realistic values were taken to represent a WiMAX network. In our analysis; we have shown how access delay will vary with changes in the number of SS; CS and probability of transmission. Network operators could use these values in the planning of WiMAX networks.

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## **Анализ задержки доступа к интервалу запроса полосы в сетях WiMAX**

**Аннотация.** В статье исследуется один из возможных аспектов деградации качества обслуживания в сетях WiMAX – такой, как задержка в выделении запрашиваемой полосы абонентским устройствам. Определяющий вклад в такую задержку авторы видят в состязательном характере доступа к интервалу запроса полосы в кадре восходящего звена. Актуальность данной статьи определяется тем, что опубликованные технические требования WiMAX оставляют вопрос определения алгоритмов доступа к состязательным слотам запроса полосы открытым, а возрастающая абонентская населенность сетей WiMAX и расширяющееся разнообразие услуг требуют все более частого обращения абонентских станций к механизму запроса полосы. Статья предлагает математическую модель для оценки задержки в оказании услуги за счет состязательного характера доступа к интервалу запроса полосы. Алгоритм вычисления средней задержки может быть использован для определения задержки в обслуживании приложения в зависимости от числа абонентских станций, размеров интервала запроса полосы и вероятности передачи запроса полосы каждой из абонентских станций. Предложенная в статье модель может быть полезной операторам сетей WiMAX для определения размеров абонентской базы и/или величин интервала запроса полосы при гарантированном качестве обслуживания конкретных приложений.

**Ключевые слова:** WiMAX; запрашиваемая полоса; состязательный слот; средняя задержка; качество обслуживания; планирование алгоритма; абонентское оборудование.

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