J Inf Process Syst, Vol.10, No.4, pp.568~580, December 2014
http://dx.doi.org/10.3745/JIPS.03.0016

ISSN 1976-913X (Print)
ISSN 2092-805X (Electronic)

Performance Evaluation of the WiMAX Network under a Complete Partitioned User Group with a Traffic Shaping Algorithm

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Abstract—To enhance the utilization of the traffic channels of a network (instead of allocating radio channel to an individual user), a channel or a group of channels are allocated to a user group. The idea behind this is the statistical distribution of traffic arrival rates and the service time for an individual user or a group of users. In this paper, we derive the blocking probability and throughput of a subscriber station of Worldwide Interoperability for Microwave Access (WiMAX) by considering both the connection level and packet-level traffic under a complete partition scheme. The main contribution of the paper is to incorporate the traffic shaping scheme onto the incoming turbulent traffic. Hence, we have also analyzed the impact of the drain rate of the buffer on the blocking probability and throughput.

Keywords—Blocking Probability, CAC, Complete Partition Scheme, Subscriber Station, Throughput

1. INTRODUCTION

The 4G mobile is aimed at providing wireless communication based on an internet protocol that is capable of transmitting data at a speed ranging from 100 Mbps to mobile users and 1 Gbps to stationary users. According to IMT-A, 4G mobile devices can be used for digital voice and rich media, which includes things like web pages with streaming videos or expandable banners, and can also assure the security of their transmission. Both Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE) promise higher speed and capacity, as compared to earlier 3G and wireless broadband network standards and they offer peak data rates of 128 Mbps for a downlink and 56 Mbps for an uplink, respectively.

An important factor in the competition between different wireless technologies is the capability of meeting quality of service (QoS), which actually indicates some real-time traffic parameters, such as throughput (related to bandwidth), packet loss (related to reliability), delay, and jitter. The LTE, which is an initialization of long-term evolution, is marketed as 4G LTE. It is a standard for the wireless communication of high-speed data for mobile phones and data terminals with guaranteed QoS. It is based on the GSM/EDGE and UMTS/HSPA network technologies and

Manuscript received August 19, 2013; first revision December 24, 2013; accepted March 03, 2014; onlinefirst October 28, 2014.
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provides higher link capacity using different radio interfaces together with the core network. In [1], the machine type communication (MTC) traffic of LTE is modeled based on a semi-Markov chain. The authors of [1] derived the stationary probability states and holding time for Poisson's traffic by considering the active and sleeping states of the network.

WiMAX is a technology that is aimed at providing wireless data over long distances with guaranteed QoS. It is based on the IEEE 802.16 standard discussed in [2-5]. With the ongoing deployment of different WiMAX technology all over the world, WiMAX is going through the evolution and adaptive processes in order to keep up other technologies. Nowadays, mobile WiMAX has emerged to cope with the demand of 4G mobile (high speed wireless data) based on OFDMA of IEEE802.16. In [6], the impact of channel bandwidth, accesses technique, use of array antenna, and the retransmission scheme on video traffic is analyzed explicitly. A similar analysis is found in [7], which looks at the following two important problems of multimedia traffic: the maximization of video quality and minimizing energy consumption.

There are numerous traditional models for the traffic of a subscriber station. From among them, the threshold-based Connection Admission Control (CAC) algorithm is the most popular. For example, [8] deals with WiMAX traffic using the Batch Markov Arrival Process (BMAP). In thiscase the authors only considered the transition matrix of a queue to evaluate the packet dropping probability and throughput. In [9,10], the authors considered the following two CAC schemes: threshold-based and queue-aware CAC schemes at a subscriber station. A two-dimensional (2D) Markov chain was used (connection vs. queue) to get the probability state of a subscriber station. In this paper we consider both the connection and queue level transition matrix. We multiplied the connection level and packet level transition matrix to find out the final transition matrix. Finally, by applying the traffic shaping technique with this algorithm we determined the network performance in context of the blocking probability and throughput.

Since WiMAX uses OFDMA where orthogonal sub-carriers are mutually disjoint, therefore, each subcarrier seems to be individual link to a user. Hence, the complete partition scheme is realistic thinking for the traffic model of a subscriber station in the event of the arrival of the offered traffic of a group of users at the station. Again, a user group under the subscriber station shares the common queue. Hence, it resembles a complete sharing scheme. Since the probability of a queue overflowing is very small the performance solely depends on the availability of channels/BW to provide immediate service. Therefore, the complete partitioning scheme of the paper seems to be a fixed network, but in actual sense, the traffic model serves the WiMAX traffic of the subscriber station. A similar concept (i.e., a combination of the connection level and queue level matrix) is available for group of users in [11-13]. However, this paper enhances the work with the flow control of traffic. The concept of the application of a special traffic shaping leaky bucket and token bucket scheme in IEEE 806.16 is found in [14,15].

The paper is organized as follows: Section 2 deals with the theoretical analysis of the subscriber station traffic of a WiMAX network and the incorporation of a traffic shaping scheme to evaluate the performance of the network. Section 3 depicts the results that are pertinent to the system model and finally, Section 4 concludes the paper.

2. SYSTEM MODEL

2.1 Connection Admission Control Algorithm

We considered a subscriber station where the combined traffic from a group of users is accumulated in a single queue and where the traffic is carried through multiple connections. The call admission control scheme used for this type of subscriber station uses the following two criterions to accept or reject a connection: 1) if the number of connections exceeds the threshold *N* then the newly arrived user is rejected, and 2) if the length of queue exceeds the threshold then any new connection is rejected.

2.1.1 Transition matrix for the queue

The transition matrix **P** of a subscriber station is expressed as [8]:

$$\mathbf{P} = \begin{bmatrix} \mathbf{T}_{0,0} & \cdots & \mathbf{T}_{0,A} & & & \\ \vdots & \vdots & \ddots & \ddots & & \\ \mathbf{T}_{R,0} & \cdots & \mathbf{T}_{R,R} & \cdots & \mathbf{T}_{R,R+A} & \\ \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\ & \mathbf{T}_{x,x-R} & \cdots & \mathbf{T}_{x,x} & \cdots & \mathbf{T}_{x,x+R} \\ & \ddots & \ddots & \ddots & \ddots & \ddots \end{bmatrix}, \tag{1}$$

where each element of the matrix **P** is another matrix $\mathbf{T}_{x,y}$. The indices x and y indicate the following: the length of queue is *x* in the current frame and *y* is in the next frame. $\mathbf{T}_{x,y}$ is expressed as the product of the connection level and the queue level transition matrix. Using the traffic shaping model from the previous section, we derive the diagonal queue level transition matrix as:

$$\mathbf{V}_{00} = \begin{bmatrix} v_{00}(0) & & & & \\ & v_{00}(1) & & & \\ & \ddots & & & \\ & & & v_{00}(r) & \\ & & & & \ddots \end{bmatrix}, \tag{2}$$

where $v_{00}(n) = u(0, x) + u(1, n)$ and:

$$u(x, n) = \frac{\left(\frac{\lambda}{gn}\right)^{x} e^{-\lambda/g}}{x!},$$

$$\mathbf{V}_{xy} = \begin{bmatrix} v_{xy}(0) & & & & \\ & v_{xy}(1) & & & \\ & \ddots & & & \\ & & & v_{xy}(r) & \\ & & & & \ddots \end{bmatrix}, \quad v_{xy}(n) = \begin{cases} \dfrac{(\frac{\lambda}{gn})^{y-x+1}.e^{-\lambda/ny}}{(y-x+1)!}; x<y; x\neq 0, y\neq 0 \\ \{(\frac{\lambda}{gn}).e^{-\lambda/g}\}^{x-y}; x>y; x\neq 0, y\neq 0 \\ \frac{\lambda}{gn}e^{-\lambda/ny}; x=y; x\neq 0, y\neq 0 \end{cases} \tag{3}$$

2.1.2 Transition matrix for the connection

The connection level transition matrix is expressed as follows [9,10]:

$$\mathbf{Q} = \begin{bmatrix} q_{0,0} & q_{0,1} & & & \\ q_{1,0} & q_{1,1} & q_{1,2} & & \\ \ddots & \ddots & \ddots & & \\ & q_{C-2,C-1} & q_{C-1,C-1} & q_{C-1,C} \\ & & q_{C-1,C} & q_{C,C} \end{bmatrix}, \tag{4}$$

where each row indicates the number of ongoing connections. The elements of this matrix can be obtained as follows:

$$\begin{aligned} q_{N,N+1} &= f_1(\rho)\times(1-f_1(c\mu)), \quad c=0,1,...., N-1; \\ q_{N,N-1} &= (1-f_1(\rho))\times f_1(c\mu)), \quad c=1,2,...., N; \\ q_{N,N} &= f_1(\rho)\times f_1(c\mu)+(1-f_1(\rho))\times(1-f_1(c\mu)), \quad c=0,1,...., N-1; \end{aligned} \tag{5}$$

where the probability that a Poisson event with average rate λ occurs during the interval T can be obtained as follows:

$$f(x,\rho) = \frac{\rho^x e^{-\rho}}{x!}, \tag{6}$$

where $\rho = \lambda T$ as the offered traffic.

We obtain the matrices $P_{x,y}$ by combining both the connection-level and the queue-level transitions as follows:

$$\mathbf{P}_{x,y} = \mathbf{Q}v_{x,y}, \tag{7}$$

for the case of threshold-based CAC algorithm.

Now, the steady probability vector $\mathbf{\Pi}$ can be obtained using the relations $\mathbf{\Pi}_p\mathbf{P} = \mathbf{\Pi}_p$ and $\mathbf{\Pi}_p\mathbf{e} = 1$; where $\mathbf{e}$ is a vector where all elements are 1. The dimension of the vector $\mathbf{\Pi}_p$ is 1 by $2\times(N+1)\times(Q_{\max}+1)$.

An alternate way of determining the probability matrix $\mathbf{P}_{x,y}$ using the two state MMPP model of [11,16-18], which includes a 2×2 diagonal probability matrix **D**(k), transition rate matrix **R**, and Poisson arrival rate matrix $\mathbf{\Lambda}$. The element of matrix **P** becomes:

$$\mathbf{P}_{x,y} = \sum_{s=x}^{y} (\mathbf{\Lambda} - \mathbf{R})^{-1} \mathbf{\Lambda D}(y,(x-s,0) P_{schudle}(s);$$

where $P_{schudle}(s)$ is the probability of scheduling S packets/frame at the base station. This type of model is used to serve all of the users under a BS where the number of users is large. Hence, the two state MMPP model is appropriate to evaluate $\mathbf{P}_{x,y}$. In our case, the subscriber station serves fewer users. Hence, the direct approach in (7) is adequate for analysis.

The general expression of the relation $\mathbf{\Pi}_p \mathbf{P} = \mathbf{\Pi}_p$ with $\mathbf{\Pi}_p \mathbf{e} = 1$ is derived as [19-21]:

$$\begin{bmatrix} 0 & \{P_{21}-(P_{11}-1)\} & \{P_{31}-(P_{11}-1)\} & \cdots & \{P_{N1}-(P_{11}-1)\} \\ \{P_{12}-(P_{21}-1)\} & 0 & \{P_{32}-(P_{22}-1)\} & \cdots & \{P_{N2}-(P_{22}-1)\} \\ \vdots & \vdots & \vdots & & \vdots \\ \{P_{1N}-(P_{NN}-1)\} & \{P_{2N}-(P_{NN}-1)\} & \{P_{3N}-(P_{NN}-1)\} & \cdots & 0 \end{bmatrix} \times \begin{bmatrix} \pi_1 \\ \pi_2 \\ \vdots \\ \pi_N \end{bmatrix} = \begin{bmatrix} 1-P_{11} \\ 1-P_{22} \\ \vdots \\ 1-P_{NN} \end{bmatrix}. \tag{8}$$

The probability of k packets waiting in queue is found as:

$$M_k = \sum_{i=0}^{2(N+1)-1} \pi_p (2k(N+1)+i) \,. \tag{9}$$

The probability of successful call is:

$$P_i = \frac{p^i}{i!} \left(\sum_{j=0}^{N} \frac{p^j}{j!} \right)^{-1} . \tag{10}$$

The average number of served VoIP packets under spectrum sensing statistics $T(x)$ is:

$$\begin{aligned} k_{av} &= \sum_{i=0}^{N} \sum_{k=1}^{4} \left\| (M_k).(1-P_i) \right\| \\ &= \sum_{i=0}^{N} \sum_{k=1}^{4} \left\| (M_k).\left(1 - \frac{p^i}{i!} \left(\sum_{j=0}^{N} \frac{p^j}{j!} \right)^{-1} \right) \right\| \end{aligned} . \tag{11}$$

The average throughput is calculated as:

$$S = k_{av} l_{VoIP}, \tag{12}$$

where l_{VoIP} is the length of PDU of VoIP.

Finally, the packet blocking probability is:

$$\beta = 1 - \frac{k_{av}}{\rho}. \tag{13}$$

2.2 Traffic Shaping Scheme

Most of the time traffic arrival in a network is found to be turbulent since a server has to deal with different traffic of different lengths and priority levels. This turbulent traffic creates excess network congestion. To combat the situation, the traffic of an irregular arrival has to be converted to the arrival of a uniform rate, which is known as traffic shaping. Let the turbulent packets arrive at an average rate of λ packets/unit time is regulated with a constant arrival rate of g packets/unit time (i.e., the interarrival time of $1/g$ time unit).

Actually, traffic shaping algorithms convert a A/B/n/K traffic to D/B/n/K (i.e., deterministic arrival rate). The two most widely used traffic shaping algorithms are leaky bucket and token bucket. In this paper, we will only consider the leaky bucket algorithm. A hole at the bottom of a bucket will drain water at a constant rate irrespective of the arrival rate of water in the bucket [22-25]. The leaky bucket in a computer is found as a finite queued buffer in the network interface card that is controlled by the operating system. The bursty traffic generated inside the computer (when it works as a source of traffic) are temporarily stored in the buffer and drains at a constant rate so that adjacent switching can tolerate that flow of traffic, as shown in Fig. 1.

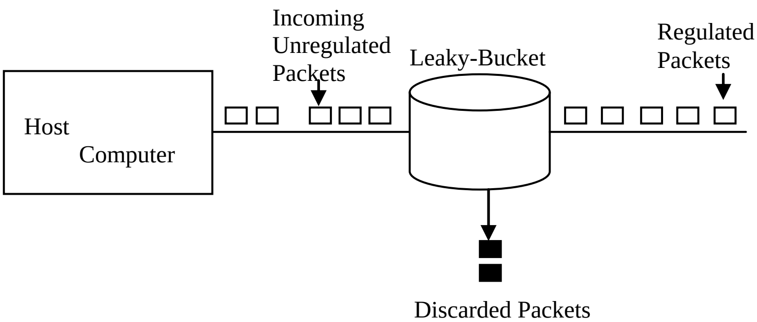

Fig. 1. Leaky bucket traffic shaping algorithm.

In the event of an overflow of incoming traffic, some packets will be discarded and in this case, some packet priority levels of can be inserted in the packet header to make the intelligent decision to save the essential packets. The traffic shaping algorithm works for both the case of packet of variable length (IP traffic of A/G/n/k) and the traffic of packet of a fixed length (ATM cell of A/D/n/K). The main parameters of the algorithm are the drain rate and buffer size of the queue. The leaky bucket scheme is sometimes modeled by the following two buffers: one for incoming packets, which is called the main buffer; and the other for authorization, which is called the grant buffer and that resembles the leaky bucket in Fig. 2.

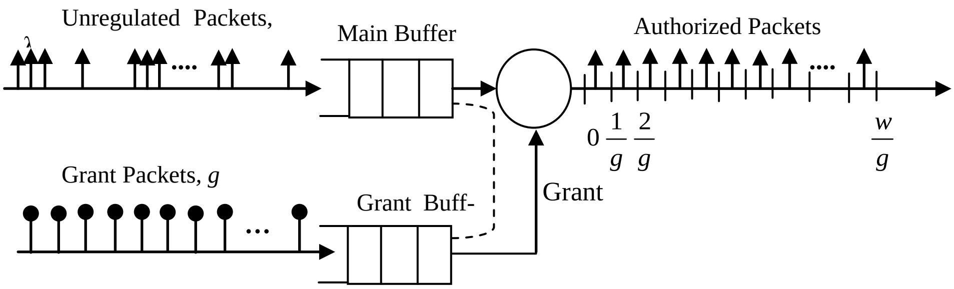

Fig. 2. Leaky bucket traffic shaping algorithm with a queuing model.

Let us now define the traffic parameters of the traffic shaping technique discussed above: λ is the arrival rate of irregular or turbulent traffic at the main buffer; g is rate of authorization grants or the drain rate of leaky bucket; and ω is size of the grant buffer or bucket, which can be adjusted based on the pattern of the offered traffic.

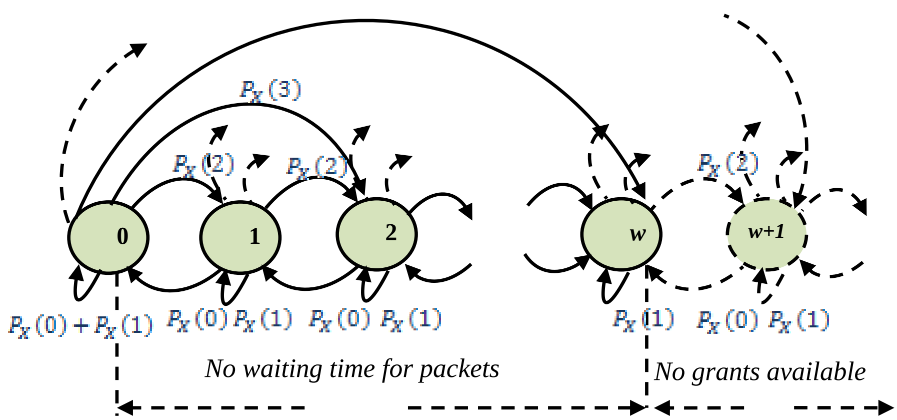

Fig. 3. State transition of leaky bucket traffic [18].

The state transition chain of a leaky bucket is shown in Fig. 3 [26-28], where each state of the chain indicates the number of packets inside the bucket. Since the size of the bucket is w, any probability state $i \leq w$ is the in-service state and the states $i > w$ are the states in queue. We know that the arrival traffic is bursty. Therefore, a transition may take from any state i to $(i + k)$ where i = 0, 1, 2… and k = 1, 2, 3,…. Here, $P_X(x)$ is the probability of x packet arrivals in $1/g$ seconds that can be calculated from Poisson's probability density function (pdf). Again, P_i is the steady probability state of the Markov chain, which is in state i, and P_{ji} is the transition probability from any state j to a state i. According to the concept of the traffic above, the probability $P_X(1)$ will keep a state unchanged. Therefore, the transition probability at state 0 has two components:

$$P_{00} = P_X(0)+P_X(1). \tag{14}$$

The state 0 can be connected to any state $i \le w$, by:

$$P_{0i} = P_X(i+1) \text{ for } \quad i \ge 1. \tag{15}$$

The transition probability in generalized form is expressed as:

$$P_{ij} = \begin{cases} P_X(i-j+1) & \text{for} \quad j \le i+1 \\ 0 & \text{for} \quad j > i+1 \end{cases} \tag{16}$$

Applying a node equation on state P_0, we have:

$$P_0 = P_X(0)P_1 + [P_X(0)+P_X(1)]P_0. \tag{17}$$

Similarly, node equation on P_1 is:

$$P_1 = P_X(2)P_0 + P_X(1)P_1 + P_X(0)P_2. \tag{18}$$

In generalized form, we can write:

$$P_i = \sum_{j=0}^{i+1} P_X(i-j+1)P_j \qquad i \ge 1. \tag{19}$$

Applying Little's formula the mean waiting period of a packet, $E[T]$ is:

$$E[T] = \frac{1}{g}\sum_{i=w+1}^{\infty}(i-w)P_i. \tag{20}$$

A similar analysis can be done for a token bucket algorithm by only changing the termination probability, such as the arrival probability.

3. Results and Discussions

The probability states for g = 2 ms and g = 4 ms are shown in Fig. 4 for four sub matrices each at a size of 6×6, which reveals four symmetric sections on the bar graph. For the lower arrival rate, the shape of the probability states are closed to exponential because it follows Poisson's pdf where for the larger arrival rate of g = 4ms, the profile of the probability state deviates from the exponential because of the peaked nature of the traffic (the variance is greater than the mean value).

Fig. 5 depicts the blocking probability (packet congestion probability) against the offered traffic in Erlangs taking “the number of allocated channels to the user group” (considered completely portioned traffic with other groups in the network) and the “packet arrival rate of hosts after applying the leaky bucket algorithm” as parameters. The value of traffic parameters taken are as follows: N = 5, ρ = 5 Erls, μ =12 packets/s, g = 4 ms, λ = 12 packets/s, and c = 1, 2, …, 5.

First of all, the blocking probability decreases with an increase in allocated traffic channels as the convention of teletraffic engineering. We are more interested in the impact of a mismatch between the packet arrival rate and its drain rate from the buffer. Here, the interval between the two adjacent packets after traffic shaping is 1/g ms (i.e., the arrival rate of a packet from the host is g packets/ms). If there is an increment in g (arrival rate of packets) the blocking probability will be high since more packets will be discarded by the traffic shaping (leaky bucket) algorithm to avoid an excess delay of the jitter of real time traffic, which is visualized in Fig. 2. This

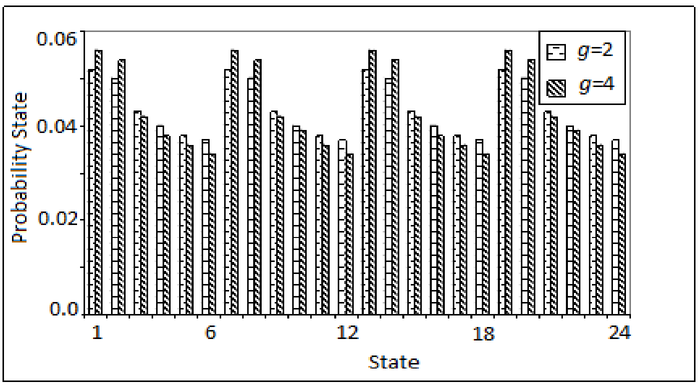

Fig. 4. Probability states of traffic under g = 2 ms and g = 4 ms.

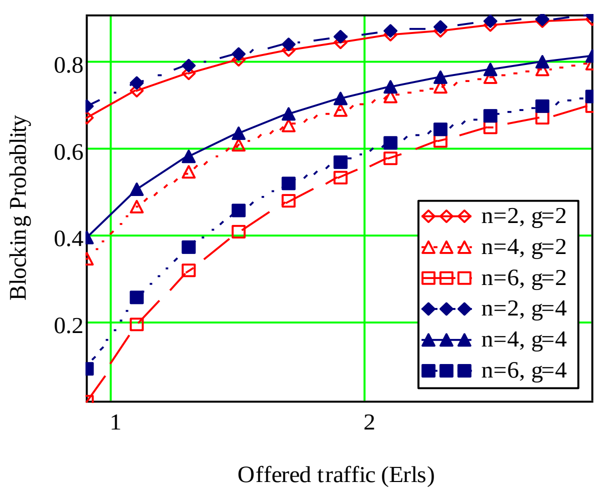

Fig. 5. The variations of call congestion probability with changes in the allocated channels of a user group, offered traffic, and the packet arrival rate of uniformly shaped traffic.

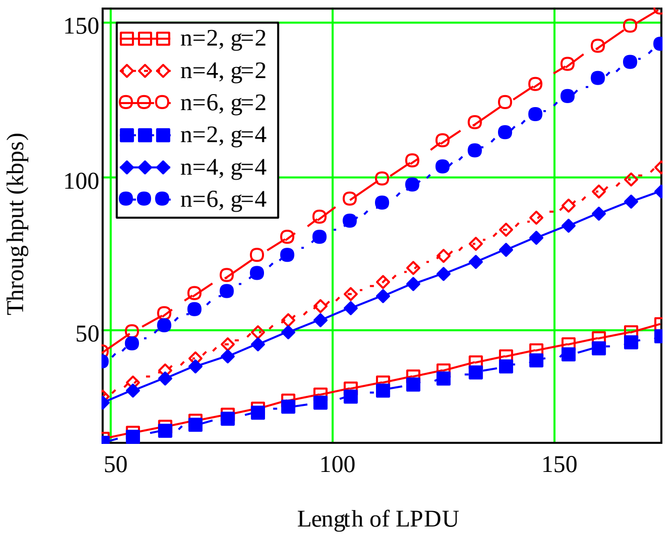

Fig. 6. The variations of throughput with changes in the allocated channels of a user group, the length of the PDU, and the packet arrival rate of uniformly shaped traffic.

situation can bring the offered traffic to a tolerable range allocating more channels to the user group, which is also visualized in the same figure. Finally, the throughput will be lowered with an increase in the service time of the packet (length of the PDU), as shown in Fig. 6. The throughput is lowered with an increase in *g* for the same reason in the case of the blocking probability that was mentioned above.

Finally, the blocking probability of turbulent traffic resembles the case of traffic without the application of a traffic shaping scheme. For the same offered traffic in Fig. 5, the blocking probability vector without a traffic shaping scheme is found to be **B** = [0.474, 0.524, 0.565, 0.6, 0.63, 0.655, 0.677, 0.697, 0.714, 0.73, 0.744], which is very close to the case of n = 4 and g = 2 curve in Fig. 2. Therefore, we have the scope for reducing the blocking probability and increments of throughput beyond this level (with the application of a traffic shaping scheme) as is visualized in Figs. 2 and 3.

4. Conclusion

The main contribution of this paper is applying a traffic shaping scheme in the subscriber station of a WiMAX network under the complete partition scheme. The impact of the drain rate on blocking probability and throughput is depicted in Section 3. The blocking probability of turbulent traffic gives a moderate result, as found in Fig. 5 or Fig. 6 (i.e., we have the scope of reducing the blocking probability or increment of throughput beyond the turbulent traffic, such as, ordinary Erlang traffic), which is the central idea of the paper. Instead of using a complete partition traffic scheme, we can apply a complete or partial sharing scheme among several subscriber stations to observe any enhancements in throughput. In this case, a multidimensional Markov chain of [10] would be helpful. The entire work can be extended in terms of the traffic for different arrivals and service time models like M/M/1/K, M/D/1/K, M/G/1/k, etc.

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