Queuing analysis for dynamic bandwidth allocation in IEEE 802.16 standard

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Abstract— **In this paper performance of dynamic bandwidth allocation in broadband wireless networks under dynamic arrival process and channel SNR is evaluated using queuing analysis framework. Adaptive modulation and coding rate based on IEEE 802.16 standard is used to adjust the transmission rate adaptively in each frame time according to channel quality in order to obtain multi-user diversity gain. Arrival process is considered to be discrete-time Markov chain which is modeled by the Markov Modulated Poisson Process (MMPP) as the traffic source. Quality of service parameters are evaluated under several allocated bandwidths to a single queue in the case of two scenarios: 1) different arrival traffic intensity, and 2) different channel quality. As expected, dynamic bandwidth allocation according to channel variations improves quality of service parameters.**

Keywords: Dynamic Bandwidth Allocation, IEEE 802.16, Performance Evaluation, Quality of Service.

I. Introduction

Broadband wireless access (BWA) has emerged as a promising technology that is capable of Internet provisioning and multimedia applications as an alternative to traditional communication networks. With advantages such as high transmission rate and predefined flexible quality of service (QoS) framework, BWA based on IEEE 802.16 is a viable technology to be used for connecting business LANs to wired Internet [1]. Also, it has recently been evolved to support mobile users [2]. Similar to cellular communication networks, in this standard a base station (BS) does provide service to users through subscriber station (SS). Since BWA based on this standard can be deployed more easily compared to wired access, it is being extended rapidly and preferred by users and service provides [3,4]. Radio resource management and dynamic bandwidth allocation (DBA) are critical mechanisms that affect QoS provisioning in communication networks. In order to have more diversity in the implementation of the standard, they haven't been specified in the context of IEEE 802.16. As a result, several papers have been presented to look into these areas [6, 7, and 8]. This paper addresses performance evaluation of DBA mechanism in a single queue scenario with MMPP arrival based on queuing analysis framework. By using water filling algorithm in power distribution, link rate varies with channel SNR according to IEEE 802.16 standard. It is assumed that channel SNR information is available in the SS. While the available link rate is allocated to the queue, some transmitted packets would be lost due to link error rate. By providing queuing analysis, QoS parameters are derived under static and dynamic channel SNR.

The rest of this paper is organized as follows. Section 2 presents a model for arrival process. Queue model and corresponding transition matrix are presented in section 3. In section 4 performance of DBA mechanism is evaluated versus arrival traffic intensity and channel quality for static and dynamic channel respectively. Section 5 concludes the paper.

II. Arrival Process Model

Arrival process is considered to be discrete-time Markov chain. It is modeled with the Markov Modulated Poisson Pprocess (MMPP) that captures burstiness of arrival processes as the main characteristic in multimedia [9] and Internet traffic [10]. Also, MMPP parameters that are obtainable through analytical approach is represented by transition matrix M and rate Matrix Λ as follows:

$$M = \begin{bmatrix} m_{11} & \dots & m_{1S} \\ \dots & \dots & \dots \\ m_{S1} & \dots & m_{SS} \end{bmatrix}, \quad \Lambda = \begin{bmatrix} \lambda_1 & & \\ & \dots & \\ & & \lambda_S \end{bmatrix} \tag{1}$$

${}_s$ denotes the mean arrival rate at state s *(s= 1, 2 …S)*. System time is discretized by partitioning it into non-overlapping frames with length T. Derived from M and Λ matrices, diagonal matrix ${}_a$ with elements indicated by the truncated Poisson process $f_a({}_s)$ represents the arrival probability of a *(a=0, 1, …A)* data packets during a frame time at state s by the following expression.

$$f_a(\lambda_s) = \left(\frac{\lambda_s^a}{a!}e^{-\lambda_s T}\right) / \left(\sum_{i=0}^{A} \frac{\lambda_s^i}{i!}e^{-\lambda_s T}\right) \tag{2}$$

As a result, the MMPP mean arrival rate is:

$$\lambda = \pi_m \left(\sum_{a=0}^{A} a \Lambda_a\right).1 \tag{3}$$

In which ${}_m$ is steady state rate probability matrix and can be obtained from ${}_m$ = ${}_m.M$ and ${}_m.\mathbf{1}=1$, where $\mathbf{1}$ is a column matrix of ones.

III. Queue Model and Performance Measures

For each connection a separate queue in SS with size X packets is used for buffering the packets from higher layers. The state of a queue (i.e., the number of packets in the queue

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and the state of arrival process) is observed at the beginning of each frame. A packet arriving in frame f will not be transmitted until the next frame $(f+1)$ at the earliest. The state space of queue can be defined as follows:

$$\Phi = \{(x, s), 0 \le x \le X, s \in \{1, 2, \dots S\}\} \quad (4)$$

Where x and s indicates the number of packets in the queue and the state of MMPP arrival process respectively. Also, the maximum number of packets that can enter into or depart form the queue within a frame time is represented with A and U respectively. Therefore the transition matrix P for a queue can be expressed as follows:

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & \cdots & p_{0,A} & & & \\ \vdots & \vdots & & & \ddots & & \\ p_{U,0} & p_{U,1} & & & p_{U,U+A} & & \\ & p_{U+1,1} & \cdots & & & p_{U+1,U+A+1} & \\ & & \ddots & & & \ddots & \\ & & & p_{X-A,X-A-U} & \cdots & & p_{X-A,X} \\ & & & \ddots & & & \vdots \\ & & & & p_{X,X-U} & \cdots \quad \cdots & p_{X,X} \end{bmatrix} \quad (5)$$

The matrix element $p_{x,x'}$ inside P is S×S probability matrix for the case when the number of packets changes from x in current frame to x' in the next frame. Since the size of the queue is finite, some of arrived packets will be dropped due to the lack of buffer space, as shown in the bottom part of matrix P. Also, channel error causes some of the transmitted packets not to be received. So the transmission probability matrix with x packets in the queue can be defined as $D^x = [D_0, \dots D_{U'}]$, $U' = \min(x, U)$. By considering as the probability that a transmitted packet not to be received successfully, each element D_{k+1} corresponding to the probability of transmitting k packets successfully within one frame time is obtained as follows:

$$\left[D^{(x)}\right]_{k+1} = \begin{cases} \binom{x}{k}(1-\theta)^k \theta^{x-k} & k < U' \\ \sum_{m=U'}^{x} \binom{x}{m}(1-\theta)^m \theta^{x-m} & k = U' \end{cases} \quad (6)$$

By presenting the number of input and output packets with j and k indexes during a frame time, the elements of matrix P become available as follows:

$$P_{x,x-u} = M \sum_{k-j=u} \Lambda_j \times [D^{(x)}]_{k+1} \quad (7.1)$$

$$P_{x,x+v} = M \sum_{j-k=v} \Lambda_j \times [D^{(x)}]_{k+1} \quad (7.2)$$

$$P_{x,x} = M \sum_{k=j} \Lambda_j \times [D^{(x)}]_{k+1} \quad (7.3)$$

$$x = 0,1,2\dots X, \quad u = 1,2,\dots U',$$
$$v = 1,2,\dots A, \quad k \in \{0,1,\dots U'\}, \quad j \in \{0,1,\dots A\}$$

(7.1), (7.2), and (7.3) are the transition probability matrices for the case when the number of packets in the queue decreases by u, increase by v and does not change respectively. Because of dropping effect in rows located in the bottom part of this matrix from $X\text{-}A+1$ to X, some of the elements must be modified as:

$$for(x+v > X) \Rightarrow P_{x,X} = \sum_{i=v}^{A} \hat{P}_{x,x+i} \quad (8)$$

In which $\hat{P}$ is the same as P with no dropping effect. To obtain the performance measures, the steady state probabilities for the queue would be required. When represented by $_p$, it is obtained by solving the equations $_p = {}_p P$ and $\pi_p.\mathbf{1}=1$. The matrix $_p$ containing the steady state probabilities for the number of packets in the queue and the state of arrival MMPP, can be decomposed into (x, s), i.e., the steady state probability that there are x packets in the queue and the state of MMPP arrival is s. As a result the mean queue length can be obtained from

$$\bar{x} = \sum_{x=1}^{X} x\left(\sum_{s=1}^{S} \pi_p(x,s)\right) \quad (9)$$

In the case when the number of arrival packets is greater than the available buffer space, $(v>(X\text{-}x))$, the number of dropped packets would be $(v\text{-}(X\text{-}x))$. So the mean dropped packet within a frame time is as follows:

$$\bar{x}_{drop} = \sum_{s=1}^{S}\sum_{x=0}^{X}\sum_{v=X-x+1}^{A} \pi_p(x,s)\left(\sum_{j=1}^{S} \hat{p}_{x,x+v}(s,j)\right)(v-(X-x)) \quad (10)$$

The term $\sum_{j=1}^{S} \hat{p}_{x,x+v}(s,j)$ indicates the total probability that the number of packets in the queue increases by v at every arrival state. By calculating the mean dropped packets per frame, the probability that incoming packet would be dropped is:

$$p_{drop} = \frac{\bar{x}_{drop}}{\lambda} \quad (11)$$

, Where is the average number of arrived packets per frame as showed in (3). So the queue throughput is as below:

$$\eta = \lambda(1 - p_{drop}) \quad (12)$$

In accordance to Little formula the mean queue delay is obtained as:

$$\bar{d} = \frac{\bar{x}}{\eta} \quad (13)$$

IV. Performance Evaluation

Adaptive modulation and coding is used to adjust the transmission rate adaptively in each frame in accordance to channel quality as a function of connection SNR. Table 1 lists these schemes represented by different rate IDs for IEEE 802.16.

Table 1: IEEE 802.16 Profiles

Rate ID	Modulation (coding)	Bit per Symbol	SNR (dB)
0	BPSK (1/2)	0.5	6.4
1	QPSK (1/2)	1	9.4
2	QPSK (3/4)	1.5	11.2
3	16QAM (1/2)	2	16.4
4	16QAM (3/4)	3	18.2
5	64QAM (2/3)	4	22.7
6	64QAM (3/4)	4.5	24.4

Fig. 1 points out the allocated bandwidth versus channel quality according to table 1 by considering b packets per frame for rate ID0.

Queue performances are measured under different amount of allocated bandwidth (i.e., b) and through two scenarios, a) under different traffic intensities by assuming channel SNR in the range of rate ID0 and b) under different channel qualities with constant traffic intensity. So the parameter U is constant and equal to b in the former scenario, while is variable corresponding to channel SNR in the later one. Both queue size and maximum arrival packets per frame is assumed to be 10 packets ($X=A=10$). Also, as link packet error rate is considered to be 0.005. MMPP arrival model is as follows, in which is traffic intensity. It is considered to be varied for the first scenario and constant to be 50 in the second one.

$$\Lambda = \alpha\begin{pmatrix} 1 & 0 \\ 0 & 2.2 \end{pmatrix}, \quad M = \begin{pmatrix} 0.1 & 0.9 \\ 0.2 & 0.8 \end{pmatrix} \tag{14}$$

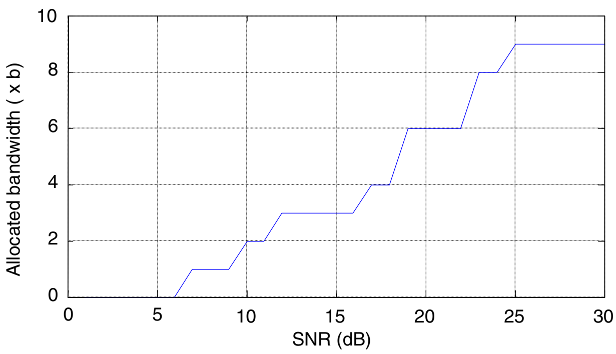

Fig. 1. Allocated bandwidth by channel quality

QoS parameters for the mentioned scenarios including queue throughput, average queue length, average delay and packet dropping probability are shown in Figs. 2-5 respectively.

As expected, when the traffic intensity increases, the queue throughput increase until it becomes saturated (Fig. 2a). At this point, the arriving packets can not be transmitted faster than the transmission rate that the channel quality allows. Also, when the channel quality improves, the transmitter can utilize higher modulation level and code rate to increase throughput (Fig. 2b). Note that if transmission rate is high enough to accommodate most of the arrival traffic, increased amount of allocated bandwidth or better channel quality will not impact the queue throughput since all the packets can be transmitted within a few frames. Also, different amount of allocated bandwidth results in different queue throughput. Average queue length, average delay and dropping probability increase as the traffic intensity increases (Figs. 3a, 4a and 5a), and decreases as the channel quality improves (Figs. 3b, 4b and 5b).

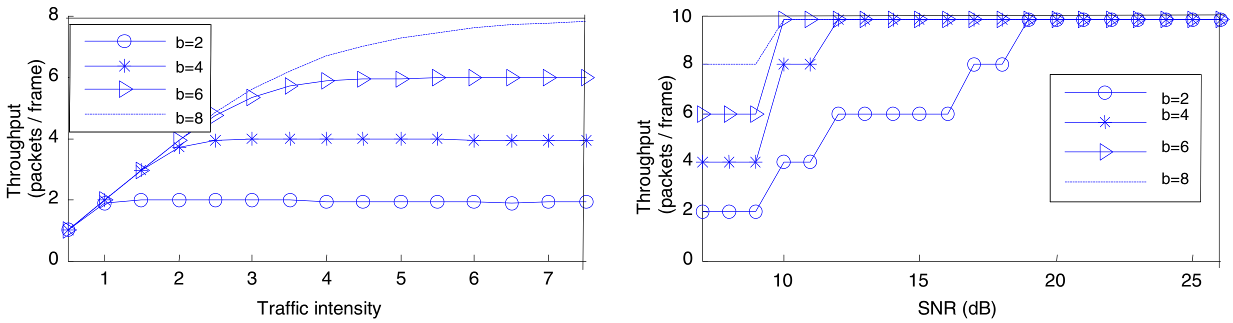

Fig. 2. Queue throughput under (a) different traffic intensities and (b) different channel qualities

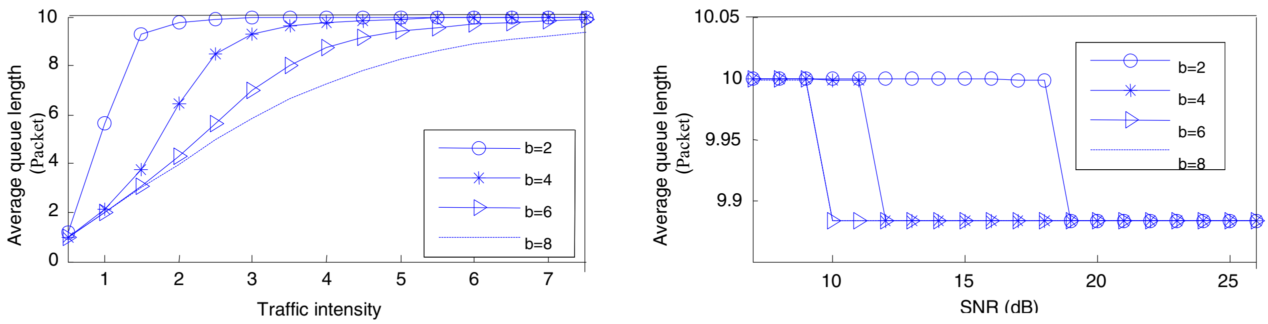

Fig. 3. Average queue length under (a) different traffic intensities and (b) different channel qualities

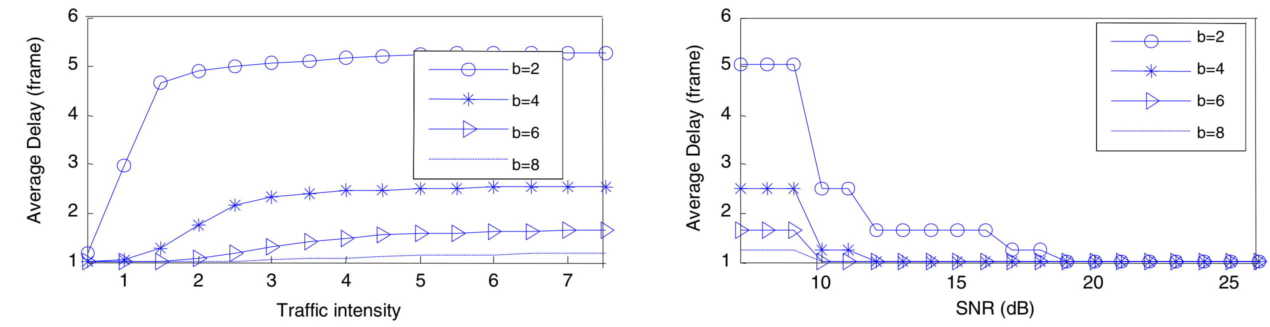

Fig. 4. Average queue delay under (a) different traffic intensities and (b) different channel qualities

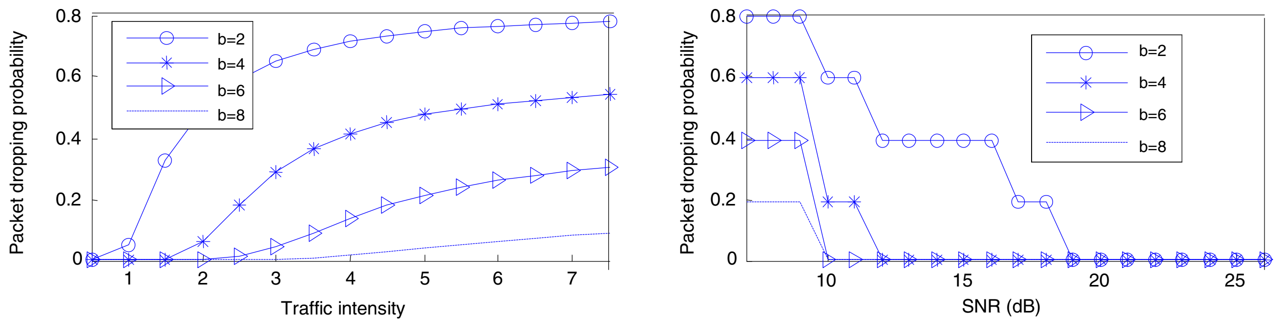

Fig. 5. Packet dropping probability (a) different traffic intensities and (b) different channel qualities

V. CONCLUSION

A queuing Analytical model has been presented to analyze the packet-level performance in IEEE 802.16-based broadband wireless access networks. It enables us to analyze quantitatively the impacts of different traffic sources based on MMPP arrival and channel qualities along with adaptive modulation and coding on QoS parameters. Increasing traffic intensity causes QoS parameters to be corrupted until they become saturated in the cost of high drop probability. This saturation occurs rapidly for link rates. Dynamically adopting link rates in accordance to channel SNR improves QoS parameters dramatically due to multi-user diversity gain in wireless communication. Also high improvement is achievable in the case of high initial link rates.

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