A Performance Model for Admission Control in IEEE 802.16

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Abstract. For systems based on connection-oriented services, such as IEEE 802.16, call admission control (CAC) strategy is essential to provide a desired level of quality of service (QoS). Although many handoff-prioritized CAC schemes, which assume a fixed channel capacity, have been introduced, this assumption is not always valid for IEEE 802.16 that uses adaptive modulation and coding (AMC). With AMC, the modulation type of a user's connection can be changed dynamically and the ongoing connection might fail due to the change of modulation. In this paper, we approach the AMC-induced CAC problem by focusing on the guaranteed connection. Three kinds of calls, new, handoff, and modulation-changed calls, are considered. We propose a modified guard channel CAC scheme that allows the modulation-changed and handoff calls to use the guard channel. Then we analyze a Markov model for the CAC scheme with long-term AMC in mind. According to the simulation results, the proposed approach reduces the call dropping probability for modulation-changed calls, which suggests the threshold of guard channels in IEEE 802.16 can be determined based on the proposed approach.

1 Introduction

IEEE 802.16 has a connection-oriented Medium Access Control (MAC) protocol [1]. In the connection-oriented systems, the CAC mechanism deals with the arrival of a new call. CAC determines whether the system accepts a new connection or not. Before the decision, CAC should confirm that the new call does not degrade the QoS of current connections and the system can provide the QoS requirements of the new call.

Recently many CAC strategies for mobile networks have been studied [2]-[6]. Due to the user mobility, ongoing calls of current cell might be handed over to another cell. However, the receiving cell might have insufficient resources due to the network overload or hostile channel conditions. Therefore if the arrival rate of new or handoff calls exceeds the capacity of a cell, it may start dropping calls or refuse handoff attempts. Since call dropping is generally considered more annoying than call blocking, many CAC mechanisms put a higher priority to handoff calls than new calls. The guard channel CAC strategy is one of those schemes that provide handoff-prioritized services for the mobile networks [5], [6]. For PCS networks, various schemes assuming a fixed amount of bandwidth were proposed. In these schemes, some of the bandwidth is exclusively reserved for handoff calls, which enables handoff calls to take precedence over new calls.

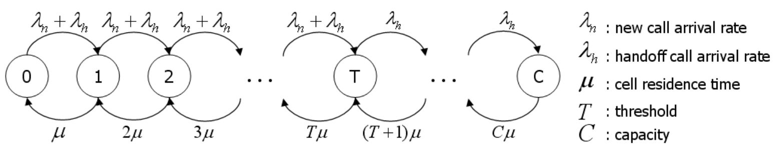

Fig. 1. State transition diagram for handoff-prioritized service

Fig. 1 shows a generalized state transition diagram for handoff-prioritized services. Traditional guard channel schemes consider a single cell with a fixed channel capacity (C), and give a higher priority to handoff calls by reserving a portion of the capacity for handoff calls. A new call can be admitted only when the occupied channels are less than a threshold (T). On the other hand, a handoff call is rejected only when all C channels are used up. Although available bandwidth is limited, a handoff call is guaranteed to get enough bandwidth for its objective. In this paper, we analyze the effects of AMC while a CAC process is running. AMC has been proved an effective technique against time-varying channel conditions and was adopted into the physical layer of several standards such as IEEE 802.16. In the next section, we describe the system model for an AMC-based CAC scheme. Analysis and simulation results are presented in Section 3.

2 System Model

The IEEE 802.16 working group on BWA(Broadband Wireless Access) develops the standards and recommended practices for broadband wireless metropolitan area networks [1]. AMC and orthogonal frequency division multiple access (OFDMA) have been adopted in the IEEE 802.16 system.

2.1 Adaptive Modulation in IEEE 802.16

The objective of AMC is to maximize the data rate by adjusting some transmission parameters to available channel information while maintaining a predetermined packet error rate. The transmission parameters can be modulation scheme, channel coding rate etc [7]. When AMC is used in a single cell, the throughput is related to the distance between two nodes. Since multi-path and user mobility inherent in mobile networks lead to fading and the change of distance, the modulation method needs to be changed to maintain the necessary packet error rate for the service.

If every connection is assumed to maintain the same bandwidth requirement, a connection using a high-order modulation, e.g, 64QAM requires less resource than those with lower-order modulations. Even if there is neither new call request nor handoff call request, change of modulation scheme may degrade QoS or even lose the connection. Therefore, a simple model such as the one in Fig. 1 fails to reflect the transmission situations faithfully, which requires the incorporation of modulation type into the CAC process. Although AMC schemes are typically designed exclusively for the physical layer, their influences will reach higher layers [8]. Our design and analysis will cover such a multi-layered aspects of AMC embedded in a CAC system.

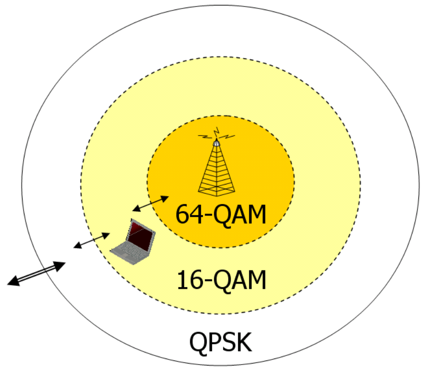

Fig. 2. Cell organization with adaptive modulation

The rates of handoff and modulation change are related to the user's velocity and the cell size he/she belongs to. To find the modulation change rate, we have to determine the cell organization like Fig. 2. A comparison of three modulation schemes is presented at table 1 and its parameters are specified in [9].

Table 1. A comparison of different transmission modes

Scheme	Spectral efficiency (b/s/Hz)	Relative coverage (%)	Relative link margin (dB)
QPSK	1.5	100	0
16-QAM	3	49	-9
64-QAM	4.5	23	-17

2.2 Markov Model for a CAC system using AMC

In the wireless AMC systems, each subscriber is assigned a different transmission mode that can be changed dynamically due to the user mobility. We consider the effects of long-term modulation changes, which have not received enough research interest in the literature of classical guard-channel CAC schemes.

To model a CAC system consisting of a single cell, analysis is carried out under the following assumptions. We consider two kinds of modulations and only guaranteed services which need the same amount of bandwidth. Three types of call requests, handoff call, new call, and modulation changed call, are modeled as independent Poisson processes. Channel holding time is assumed to be exponentially distributed. ($\mu_1 = \mu_{d1} + \mu_{h1}$, $\mu_2 = \mu_{d2} + \mu_{h2}$)

- C : The total number of mini slots as a cell capacity
- s_1, s_2 : The number of mini slots which is needed to a connection with modulation type 1 and type2, respectively
- λ_{n1}, λ_{n2} : Arrival rate of new calls with modulation type 1 and type 2, respectively
- λ_{h1}, λ_{h2} : Arrival rate of handoff calls with modulation type 1 and type 2, respectively
- $1/\mu_{d1}$, $1/\mu_{d2}$: Average cell residence time in a cell until disconnection with modulation type 1 and type 2, respectively
- $1/\mu_{h1}$, $1/\mu_{h2}$: Average cell residence time in a cell until handoff with modulation type 1 and type 2, respectively
- $1/\mu_{m1}$: Average channel holding time of a call in a cell until changing modulation from type 1 to type 2
- $1/\mu_{m2}$: Average channel holding time of a call in a cell until changing modulation from type 2 to type 1

In our guard-channel scheme, a modulation changed call takes precedence over a new call as well as a handoff call. Let g represent the proportion of the guard channel to the total bandwidth. We consider a bufferless system and a new call can only be admitted when current bandwidth usage is less than $C(1-g)$. The system reserves $g \cdot C$ of available channels as guard channels. When the resource is not enough during the process of handoff or modulation change, the call is dropped rather than degrading QoS.

In Fig. 3, shown is a state transition diagram for the number of calls in the AMC system. Each state can be represented by k_1 ,k_2, the number of calls for each modulation type. Then the state space can be denoted as $E = \{(k_1, k_2)\,|0 \leq k_1, 0 \leq k_2, 0 \leq k_1 \cdot s_1 + k_2 \cdot s_2 \leq C\}$ where k_1 represents the number of users using modulation type 1, and k_2 for modulation type 2.

From Fig. 3, we obtain the following transition rates. Let $q(k_1, k_2 : k_1', k_2')$ be the probability of translation from state (k_1, k_2) to state (k_1', k_2'). The amount of free bandwidth for a new call and a handoff call in state (k_1, k_2) can be calculated as

$$f_n(k_1, k_2) = C(1-g) - (k_1 s_1 + k_2 s_2) \quad (1)$$

$$f_h(k_1, k_2) = C - (k_1 s_1 + k_2 s_2) \quad (2)$$

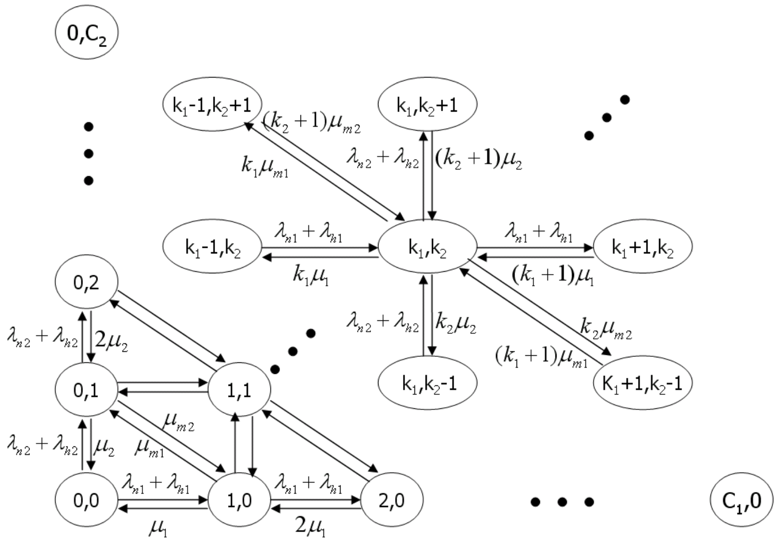

Fig. 3. Markov chain representation for the AMC system

Then we have
$q(k_1, k_2 : k_1 + 1, k_2) = \lambda_{n1} \cdot 1_{f_n(k_1+1,k_2)\geq 0} + \lambda_{h1} \cdot 1_{f_h(k_1+1,k_2)\geq 0}$
$q(k_1, k_2 : k_1, k_2 + 1) = \lambda_{n2} \cdot 1_{f_n(k_1,k_2+1)\geq 0} + \lambda_{h2} \cdot 1_{f_h(k_1,k_2+1)\geq 0}$
$q(k_1, k_2 : k_1 - 1, k_2) = \{k_1\mu_1 + k_1\mu_{m1} \cdot 1_{f_h(k_1-1,k_2+1)<0}\} \cdot 1_{k_1-1\geq 0}$
$q(k_1, k_2 : k_1, k_2 - 1) = \{k_2\mu_2 + k_2\mu_{m2} \cdot 1_{f_h(k_1+1,k_2-1)<0}\} \cdot 1_{k_2-1\geq 0}$
$q(k_1, k_2 : k_1 + 1, k_2 - 1) = k_2\mu_{m2} \cdot 1_{k_2-1\geq 0} \cdot 1_{f_h(k_1+1,k_2-1)\geq 0}$
$q(k_1, k_2 : k_1 - 1, k_2 + 1) = k_1\mu_{m1} \cdot 1_{k_1-1\geq 0} \cdot 1_{f_h(k_1-1,k_2+1)\geq 0}$
where (k_1, k_2) is a feasible state in E, and $1_{true} = 1$ when the expression is true, otherwise $1_{false} = 0$. The $q(k_1, k_2 : k_1 - 1, k_2)$ and $q(k_1, k_2 : k_1, k_2 - 1)$ have the dropping transition due to the failure of modulation change.

Let $\pi(k_1, k_2)$ be the steady state probability for state (k_1, k_2). Applying the above transition rate, the balance equation for state (k_1, k_2) can be obtained by equating the flux out of a state to that into a state.

$$
\begin{aligned}
- \; & [\lambda_{n1} \cdot 1_{f_n(k_1+1,k_2)\geq 0} + \lambda_{h1} \cdot 1_{f_h(k_1+1,k_2)\geq 0} \\
& +\lambda_{n2} \cdot 1_{f_n(k_1,k_2+1)\geq 0} + \lambda_{h2} \cdot 1_{f_h(k_1,k_2+1)\geq 0} \\
& +\{k_1\mu_1 + k_1\mu_{m1} \cdot 1_{f_h(k_1-1,k_2+1)<0}\} \cdot 1_{k_1-1\geq 0} \\
& +\{k_2\mu_2 + k_2\mu_{m2} \cdot 1_{f_h(k_1+1,k_2-1)<0}\} \cdot 1_{k_2-1\geq 0} \\
& +k_2\mu_{m2} \cdot 1_{k_2-1\geq 0, f_h(k_1+1,k_2-1)\geq 0} \\
& +k_1\mu_{m1} \cdot 1_{k_1-1\geq 0, f_h(k_1-1,k_2+1)\geq 0}] \cdot \pi(k_1, k_2) \\
+ \; & \{\lambda_{n1} \cdot 1_{f_n(k_1,k_2)\geq 0} + \lambda_{h1}\} \cdot 1_{k_1-1\geq 0} \cdot \pi(k_1 - 1, k_2) \\
+ \; & \{\lambda_{n2} \cdot 1_{f_n(k_1,k_2)\geq 0} + \lambda_{h2}\} \cdot 1_{k_2-1\geq 0} \cdot \pi(k_1, k_2 - 1)
\end{aligned}
$$

$$+ \ \{(k_1+1)\mu_1 + (k_1+1)\mu_{m1} \cdot 1_{f_h(k_1,k_2+1)<0}\} \cdot 1_{f_h(k_1+1,k_2)\geq 0} \cdot \pi(k_1+1, k_2)$$
$$+ \ \{(k_2+1)\mu_2 + (k_2+1)\mu_{m2} \cdot 1_{f_h(k_1+1,k_2)<0}\} \cdot 1_{f_h(k_1,k_2+1)\geq 0} \cdot \pi(k_1, k_2+1)$$
$$+ \ (k_2+1)\mu_{m2} \cdot 1_{k_1-1\geq 0, f_h(k_1-1,k_2+1)\geq 0} \cdot \pi(k_1-1, k_2+1)$$
$$+ \ (k_1+1)\mu_{m1} \cdot 1_{k_2-1\geq 0, f_h(k_1+1,k_2-1)\geq 0} \cdot \pi(k_1+1, k_2-1) = 0 \qquad (3)$$

From [10], the global balance equation is represented as $Q \cdot \overrightarrow{\pi} = 0$, and normalization equation as $\sum_{k_1,k_2 \in E} \pi(k_1,k_2) = 1$. The Q matrix can be generated by the above equation, and the steady state probability at each state can be also computed, which can be used for obtaining the blocking probability of a new call, a handoff call, and a modulation changed call respectively. The performance of the CAC scheme can be evaluated from the blocking probability of each type of call.

3 Numerical Result

We employ two modulations, QPSK and 16QAM. At the beginning of cell planning, the network provider may organize the area initially for QPSK and later move to 16QAM, 64QAM for higher efficiency. If the subscribers are uniformly distributed, then new call arrival rate is proportional to the size of the area. Let $\lambda_{n1} + \lambda_{n2}$ denote the new call arrival rate, ranging from 0.1 to 0.5. In a fluid flow model [11], [12], the handoff arrival rate can be expressed by $\lambda_h = \frac{\alpha\rho V L}{\pi}$, where L is the perimeter of the cell. $\alpha\rho$ is a active population density and V is the average user's velocity. The handoff departure rate can be represented by $\mu_h = \frac{16V}{\pi L}$. According to this mobility model, the handoff arrival rate is proportional to the perimeter, to which the handoff departure rate is inversely proportional. Suppose that λ_{h1} is a relative value to $\lambda_{n1} + \lambda_{n2}$, assuming that V and L are constant. λ_{h2} is set to 0 assuming no handoff arrival with high modulation types. The cell residence time for each modulation and call closure type is assumed to be exponentially distributed with mean 200 sec. Then μ_1 and μ_2 can be 1/100 1/200 respectively, also assuming no handoff departure with high modulation types. The modulation change rate can be estimated from its radius and handoff rate. μ_{m1} is related with handoff arrival rate λ_{h1}, and μ_{m2} is connected to handoff departure rate μ_{h1}.

Since the best-effort service can be always admitted without regard to the system resources, we consider the CAC operation only for the guaranteed service. We divide the bandwidth allocated for the guaranteed service into 64 blocks of time slots using OFDM or TDMA. Applying the same channel coding rate for each modulation type, the bandwidth assignment for the connection with modulation type 1 can be two blocks, and that for connection with modulation type 2 can be one block. In this case, there can be a total of 32 guaranteed connections using only QPSK modulation.

From the Markov chain on Fig. 3, we generate the state transition matrix and compute the steady state probability. From the steady state probability obtained, we calculate the call blocking probability for each call type considering the arrival rate in each state. Let P_b be the probability that an arriving call is blocked, and P_b can be calculated as

$$P_b = \sum_{j_1,j_2 \in B} \frac{\lambda \cdot \pi(j_1, j_2)}{\lambda \cdot \sum_{k_1,k_2 \in E} \pi(k_1, k_2)} \tag{4}$$

E is the total state space and B is the bounded area where arriving call will be blocked.

To verify the analytical results, 100 hours of simulations on the proposed AMC system, in which only the CAC operation in a single cell was implemented, have been performed. A set of simulations was repeated 20 times, each time with a different random number generator seed. The analytic and 95% confidence interval simulation results are shown in Figs. 4-7. Note that in all figures, the call intensity is $\rho = \frac{\lambda_{n1}+\lambda_{n2}}{\mu_{d1}+\mu_{d2}}$, which varies from about 5 to 50.

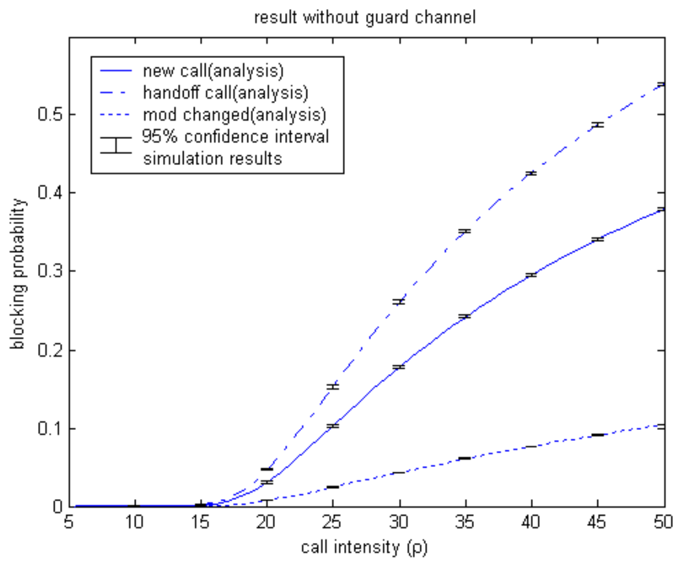

Fig. 4. Blocking probability versus call intensity without guard channels

Figs. 4 and 5 depict the blocking probability for each call type versus call intensity under different CAC schemes. In Fig. 4, shown is the blocking probability without priority, assuming no handoff calls for high modulations. Therefore the blocking probability of handoff calls is higher than that of a new call. Fig. 5 compares the blocking probability in the case of using 10% guard channels. From the figure, it is apparent that the call blocking probability increases with call intensity. The difference between Fig. 4 and Fig. 5 confirms that guard channels can help to reduce the blocking probabilities of handoff calls and modulation changed

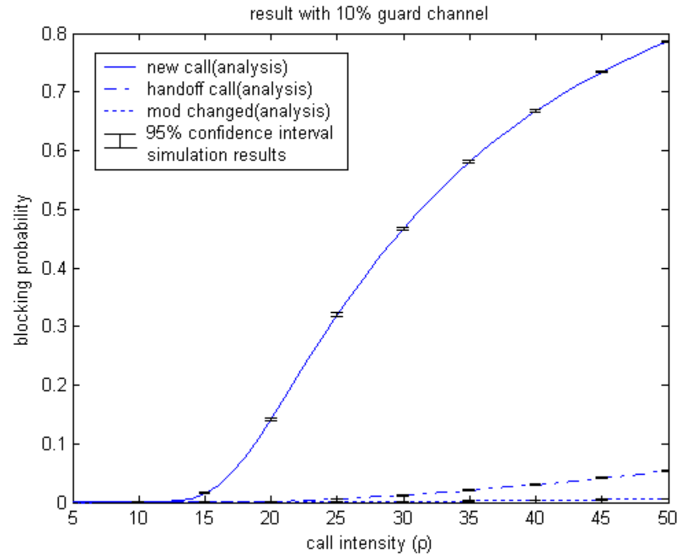

Fig. 5. Blocking probability versus call intensity with 10% guard channels

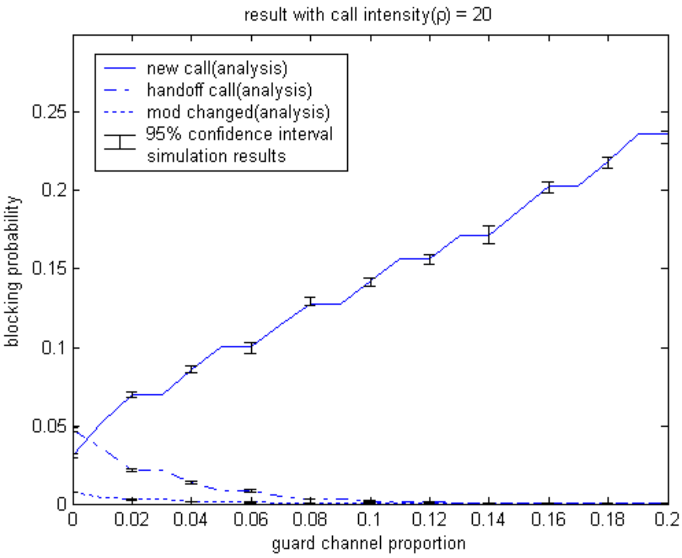

Fig. 6. Blocking probability versus the proportion of guard channels

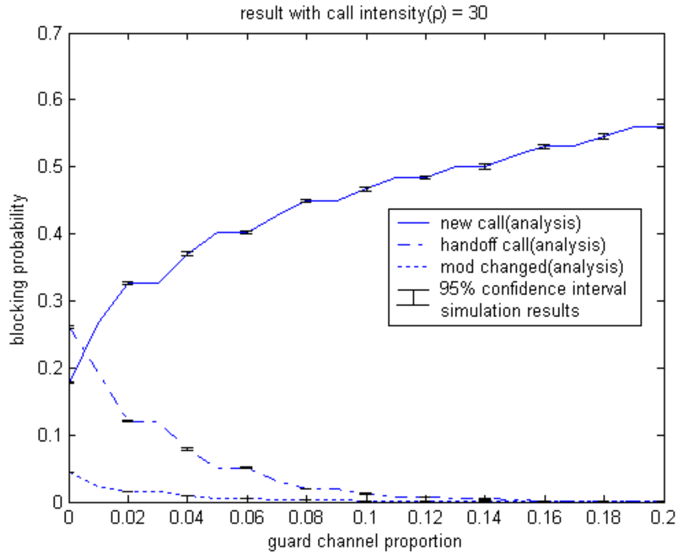

Fig. 7. Blocking probability versus the proportion of guard channels

calls. The blocking probabilities of handoff calls and modulation changed calls can be reduced at the cost of the bandwidth limitation for new calls.

In Figs. 6 and 7, shown is the blocking probability for each call type versus the relative guard channel, under different call intensities. It is observed that when the proportion of the guard channel to the total bandwidth is increased, the blocking probabilities of handoff calls and modulation changed calls are decreased. We can compute the call blocking probability of each call type with given parameters. Therefore, it can be concluded that this model is effective in deciding appropriate thresholds of guard channels for an AMC system.

4 Conclusion

CAC schemes are essential to support required QoS in the wireless mobile networks. In this paper, we investigated the AMC-induced call dropping at a CAC process. We analyzed the guard channel CAC scheme with focus on three aspects: new call arrival rates, handoff call arrival rates, and modulation changed rates. We described a Markov model for the CAC scheme under the influence of long-term AMC. Simulation results show that as the proportion of guard channels increases, blocking probabilities of handoff calls and modulation changed calls decrease. This improvement was achieved by limiting the bandwidth for new calls. In setting up of IEEE 802.16 systems, an appropriate number of guard channels should be selected to maintain the call dropping ratio close to the intended level. Our model and analysis can be a guide to configure those

AMC-based wireless networks. For future work, the analysis and simulation in this paper should be confirmed with real IEEE 802.16 networks. We will have to classify the connections further with various QoS parameters such as traffic class, delay, maximum rate, guaranteed rate, and packet loss rate. For systems with more than two modulation types, it is necessary to extend the analysis to additional dimensions.

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