

A Link Adaptation Based Call Admission Control Algorithm for OFDMA Systems

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Abstract— This paper presents a new call admission control (CAC) algorithm that takes into account the effect of mobility of users and adaptive modulation and coding (AMC) scheme, which can be used in orthogonal frequency division multiple access (OFDMA) systems with link adaptation. When the cell is decomposed into several concentric circles, time-frequency resources required for various traffics can be determined accurately, while resources reserved for handoff and AMC mode changed calls/connections or even new connections can be calculated according the AMC scheme of the users, so as to guarantee the connection-level performance. The proposed algorithm can provide the quality of service (QoS) requirements by taking advantage of the probability distribution of total traffics in the cell to determine the resource consumption. The performance of the proposed algorithm is analyzed with BCMP queuing network model. The simulation results verify the packet-level and connection-level performance of the proposed CAC algorithm.

Keywords— call admission control; orthogonal frequency division multiple access; quality of service; adaptive modulation and coding; queuing networks

I. INTRODUCTION

Call Admission Control (CAC) plays an important role to support multiple types of applications with different QoS requirements in broadband wireless networks such as WiMAX and LTE networks. The CAC schemes aim to maintain the delivered QoS of the admitted calls by limiting the number of ongoing calls in the systems [1]. It needs to maintain the call-level and packet-level performance simultaneously to satisfy the QoS requirements of various services, and utilize the available resources efficiently.

For most of the broadband wireless networks, link adaption is employed as a key technology to optimize spectrum utilization. It can be implemented by an Adaptive Modulation and Coding (AMC) scheme. When the wireless channel quality changed, different AMC schemes will be utilized to adapt a user's transmission data rate so as to optimize spectrum utilization. This may result in dynamic resource

consumption and system capacity. Moreover, most non-voice services have variable bit rates which will also lead to variable resource requirements. Either of the properties above makes it a big challenge to design an efficient CAC algorithm which needs to take into account both the mobility of the users and their variable transmission rate requirements.

Many papers have proposed OFDM based CAC algorithms. Paper [2, 3] uses different bandwidth reservation strategies for different connections to guarantee their connection-level QoS. Reference [4] provides a CAC algorithm dedicated to support voice over IP service, in which the VoIP traffic with different priorities will have different admission strategies and therefore different performance. However, the time-varying resource requirements and cell capacity due to the use of link adaptation are not taken into consideration. In reference [5], a power reservation based admission control scheme for inter-cell and intra-cell handoff calls is proposed which considers a user's AMC level to calculate the transmit power of the base station. But it is only suitable for constant bit rate services. Paper [6] admits a connection according to the mean load of the cell in which intra-cell mobility is introduced to estimate the cell load. This algorithm supposes that the total user number in a cell is constant and no QoS requirement is considered.

In this paper, we propose a QoS-aware CAC algorithm for OFDMA based system which also considers the influence of the usage of link adaptation. We decompose the cell into several concentric circles according to the employed AMC schemes. A method is proposed to calculate the time-frequency resources required for each connection, which is based on both the QoS requirements and the AMC scheme so that the performance of packet-level can be satisfied. Moreover the admission strategies vary with different connections to meet the requirements of the connection-level performance and to improve the system resource utilization as well.

The rest of this paper is organized as follows. Section II gives the system model. In section III we present the QoS aware CAC algorithm. Section VI gives the performance analysis using queuing network model. Section V gives results

of simulations. Finally the conclusions are drawn in Section VI.

II. SYSTEM MODEL

In an OFDMA system, the intra-cell movement of users and time-varying user distribution has much influence on the cell capacity. The path loss which is determined by the distance between user and base station (BS) is a major factor that affects the SNR (Signal to Noise Ratio) and corresponding AMC mode. When a user moves from one position to another, the AMC mode would be changed to maintain the necessary bit error rate. A lower order AMC mode requires more time-frequency resources than the higher one for the same data rates requirement. So AMC mode changed connections need to be incorporated into the CAC algorithm to prevent connections from dropping when the user moving from a higher AMC mode to a lower AMC mode. In the proposed CAC algorithm, we classify the connections into three types, i.e. new connections, handoff connections and AMC mode changed connections.

In this paper, we divide the cell into N concentric rings of radius L_i as shown in Figure 1. The connections with the same AMC mode i belong to the same ring i . We define ring i as the area between two adjacent circles of radius L_i and L_{i+1} . L_i can be determined by the required SNR for AMC mode i and an appropriate channel model.

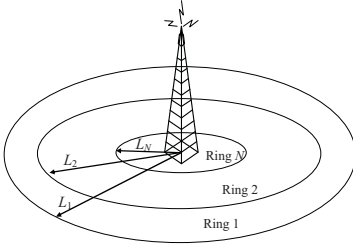


Figure 1. Cell decomposition into rings

In an OFDMA system, resource allocation is based on a sub-channel/time-slot pair. We consider a user in ring i request a connection j with bandwidth requirement C_{ij} . The required time-frequency resources can be given by:

$$s_{i,j} = \frac{C_{i,j}}{b_i \cdot N_s} \quad (1)$$

where b_i denotes the information bits that can be carried on one subcarrier by the user in ring i when using AMC mode i . N_s is the number of subcarriers in one minimum unit for resource allocation.

The total time-frequency units allocated to the admitted connections in a cell can be given by

$$X = \sum_{i=1}^N \sum_j s_{i,j} \quad (2)$$

When a handoff user arrives, or a user moves from ring $i+1$ to ring i , it will need more resource units to maintain the QoS requirements. An appropriate resource reservation strategy can guarantee the low dropping probability of both handoff

connections and AMC mode changed connection [7]. We set the CAC criteria as follows:

$$P[X + S_R > S] \leq \varepsilon \quad (3)$$

where ε is the admissible overflow probability. S is the total time-frequency resource units in one allocation period, which will remain the same even taking the AMC scheme into consideration. For a new connection, S_R is the reserved resource units for handoff and AMC mode changed connections.

III. PROPOSED CAC SCHEME

Supporting various services with different QoS requirements is of prime importance in broadband wireless networks. The proposed CAC algorithm aims at supporting multiple QoS services and adapting to the radio conditions so as to satisfy the packet-level and connection-level performance and to utilize the available resources efficiently. We first calculate the required resources for different kinds of services. Then the resources reserved for different connections will be determined. Finally, the procedure of the proposed CAC scheme is given.

A. Determination of the required resources

Some CAC algorithms such as [3, 8] utilize the mean data rate or minimum and maximum data rate of the services to calculate the required resources. It can work well for the constant bit rate services such as voices, or some data services such as FTP which have the requirements of the minimum reserved bandwidth. But for variable bit rate services such as MPEG video, the bit rate of a service flow has a large variance. The calculation of the occupied resources for this kind of services needs to consider the characteristics of the time-varying data rate.

We assume that the connections are independent. If the number of the admitted connections becomes sufficiently large, according to the Central Limit Theorem, the sum of the bit rates of all admitted connections will be tend towards a normal distribution. The total bandwidth requirements in ring i can be expressed as

$$C_i = \sum_j C_{i,j} \quad (4)$$

Then C_i follows normal distribution. Let M_i and V_i be the mean and variance of C_i , we have

$$M_i = \sum_j M_{i,j} \quad (5)$$

$$V_i^2 = \sum_j V_{i,j}^2 \quad (6)$$

where $M_{i,j}$ and $V_{i,j}$ is the mean and variance of bandwidth requirement for the connection j in ring i , respectively.

The total time-frequency resource units allocated to the admitted connections can be as follows:

$$S_u = \sum_{i=1}^N \sum_j s_{i,j} = \sum_{i=1}^N \frac{C_i}{b_i N_s} \quad (7)$$

Assuming that the connections arriving at different rings are independent, S_u will follow the normal distribution with mean M_s and variance V_s , where

$$M_s = \sum_i \frac{M_i}{b_i N_s} \quad (8)$$

$$V_s^2 = \sum_i \frac{V_i^2}{b_i^2 N_s^2} \quad (9)$$

So that the equation (3) can be express as

$$\begin{aligned} P[S_u > S - S_R] &= 1 - F(S - S_R) \\ &= 1 - \Phi\left(\frac{S - S_R - M_s}{V_s}\right) \leq \varepsilon \end{aligned} \quad (10)$$

where $F(x)$ is the probability distribution function of S_u , $\Phi(x)$ is the probability distribution function of a standard normal random variable. So the criteria for CAC can be expressed as:

$$M_s + \beta V_s \leq S - S_R \quad (11)$$

where β is the probability that a standard normal random variable exceeds ε .

B. Determination of the reserved resources

The proposed CAC algorithm reserves an amount of resources for the handoff and AMC mode changed connections in order to guarantee their connection-level performance.

For the handoff connections, the reserved resource units S_R will be set to ensure that at least one handoff connection with the maximum bandwidth requirement could be admitted. So

$$S_R = \alpha \left(\frac{M_{\max}}{b_1 N_s} + \beta \sqrt{\frac{V_{\max}^2}{b_1^2 N_s^2}} \right) \quad (12)$$

where $\alpha \geq 1$ is the resource reservation coefficient. $M_{\max}$ and $V_{\max}$ are the mean and variance of the maximum bandwidth requirement of the handoff connections.

For the AMC mode changed connections, we need to consider the amount of increased resources when a user moves from ring $i+1$ to i .

We suppose that the number of AMC mode changed connections in ring i is proportional to the area of ring i . The handoff connections are assumed to locate in ring 0 with the larger circle of radius L_0 and the smaller one of radius L_1 , where $L_0 = 2L_1 - L_2$. When a connection changes its AMC mode from $i+1$ to i , more resource units are needed in order not to drop that connection. We can calculate the increased units S_{AMC}^i as follows:

$$\frac{S_{AMC}^i}{S_R} = \left(\frac{b_i}{b_i} - \frac{b_i}{b_{i+1}} \right) \left(\frac{L_i^2 - L_{i+1}^2}{L_0^2 - L_1^2} \right), 1 \leq i < N \quad (13)$$

Table 1 gives an example to show the ratio between S_{AMC}^i and S_R when using the path loss model for macro cells [9] and the target SNR in [10] to get the radius L_i .

The table illustrates that the increased resource units due to the change of AMC mode for a connection are relatively small compared to the arrival of a handoff connection. Moreover,

there will be some resource units released when a user moves from ring i to $i+1$. So we let S_R be the reserved resources for both handoff and AMC mode changed connections to reduce their dropping probability.

TABLE 1. THE RELATIONSHIP BETWEEN S_{AMC}^i AND S_R

i	1	2	3	4	5
$\frac{S_{AMC}^i}{S_R}$	0.2786	0.0807	0.0765	0.0268	0.0030

Generally, handoff and AMC mode changed connections take precedence over new connections, and new connections are not allowed to occupy the reserved resource. In this paper, we propose an admission strategy for new connections to improve the resource utilization. The scheme decides whether to admit a new connection according to the following procedures:

If $M_s + \beta V_s \leq S - S_R$, then admit the new connection;

If $S - S_R < M_s + \beta V_s \leq S - \delta S_R$, the new connection in ring i will be admitted with the admission probability a_i , where $0 \leq a_1 \leq a_2 \leq \dots \leq a_N \leq 1$, and $\delta \in (0,1)$ indicates that a portion of reserved resources can be occupied by new connections;

If $M_s + \beta V_s > S - \delta S_R$, reject the new connection.

We set a larger admission probability for the connections with higher order of AMC mode to increase the system capacity because these connections require fewer resources to achieve the same data rates than the connections with lower order of AMC mode.

C. Procedure of the proposed CAC algorithm

The proposed CAC algorithm takes the following steps to admit AMC mode changed connections, handoff connections and new connections.

Step 1: Initialize the mean and variance of time-frequency resource units allocated to the admitted connections, i.e. $M_s=0$, $V_s^2=0$, and calculate the reserved resource S_R ;

Step 2: When a new connection or an AMC mode changed connection arrives, its AMC mode i and the mean and variance of the request bandwidth of the connection will be acquired. Then calculate the mean and variance of total resource units if admitting the connection according to equation (8) and (9);

Step 3: Decide whether to admit the connection according to the connection type as follows:

For an AMC mode changed connection or a handoff connection:

If $M_s + \beta V_s \leq S$, admit the connection;

If $M_s + \beta V_s > S$, reject the connection.

For a new connection:

If $M_s + \beta V_s \leq S - S_R$, admit the connection;

If $S - S_R < M_s + \beta V_s \leq S - \delta S_R$, admit the connection with probability a_i when the connection in ring i ;

If $M_s + \beta V_s > S - \delta S_R$, reject the connect.

IV. PERFORMANCE ANALYSIS

When decomposing the cell into rings, the users' mobility and the arrival and termination of connections can be modelled as a mixed BCMP queuing network. The arrival of a handoff connection or a new connection can be viewed as a user arrives from outside the network at ring 1 and any ring according to the new connections' location in the cell. The user's intra-cell mobility can be viewed as the movement between rings. A connection moves to other cells or the termination of a connection can be seen as the departure from the network from ring 1 or any ring respectively. Each ring represents a node in the BCMP network which can provide services to the connections located in the ring if the connections can be admitted under the CAC scheme. Each connection represents a job which requests services from the node. There are three types of connections corresponding to three classes of jobs.

We suppose that there are N nodes in the network, which represent N types of AMC modes or N rings. The number of job classes denotes as $R=3$, which represents 3 types of connections. We define $r=1$ to denote the new connections, $r=2$ to denote the handoff connections, $r=3$ to denote the AMC connections. The movement of a connection of the r th type from ring i to j corresponds to a job of the r th class transferring to node j after it has been served in node i .

This BCMP queuing network belongs to a queuing network with population size constraints because a connection will be rejected if the available resources are insufficient when it arrives at the network or moves between the rings. The number of connections in each node, i.e. the state of each node is determined by the CAC strategy.

We assume the connections of the same type have the same QoS requirements, i.e. the same mean M_r and variance V_r of bandwidth request. Let k_{ir} denotes the number of connections of the r th class at node i . $\mathbf{K}_i = (k_{i1}, \dots, k_{iR})$ represents the state of node i . The number of connections in various classes, known as the population vector is $\mathbf{K} = (\mathbf{K}_1, \dots, \mathbf{K}_N)$. The set of allowable states Ω can be determined by equation (11).

We can take advantage of results in BCMP queuing network theory [11] to get the steady-state probabilities as follows:

$$\pi(\mathbf{K}) = \pi(\mathbf{K}_1, \mathbf{K}_2, \dots, \mathbf{K}_N) \\ = \frac{1}{G(\Omega)} \prod_{i=1}^N \prod_{r=1}^R \frac{1}{k_{ir}!} \cdot \left(\frac{\lambda_{ir}}{\mu_{ir}} \right)^{k_{ir}}, \mathbf{K} \in \Omega \quad (14)$$

$$G(\Omega) = \sum_{\mathbf{K} \in \Omega} \prod_{i=1}^N \prod_{r=1}^R \frac{1}{k_{ir}!} \cdot \left(\frac{\lambda_{ir}}{\mu_{ir}} \right)^{k_{ir}} \quad (15)$$

where λ_{ir} is the arrival rate of connections of the r th class at the i th node. μ_{ir} is the service rate of the i th node for jobs of the r th class.

Let $\mathbf{K}_{i1}^+$ be the state description when a new connection arriving at node i , then

$$\mathbf{K}_{i1}^+ = (k_{11}, \dots, k_{(i-1)1}, k_{i1} + 1, k_{(i+1)1}, \dots, k_{N1}, k_{12}, \dots, k_{N2}, k_{13}, \dots, k_{N3}) \quad (16)$$

So the new connection blocking probability P_{nb} can be expressed as the probability of the system in the state where a new connection is rejected:

$$P_{nb} = \sum_{i=1}^N \sum_{\mathbf{K} \in \mathbf{B}_{i1}^+} \pi(\mathbf{K}) \quad (17)$$

where

$$\mathbf{B}_{i1}^+ = \{\mathbf{K} | \mathbf{K} \in \Omega, \mathbf{K}_{i1}^+ \notin \Omega\} \quad (18)$$

Let $\mathbf{K}_{i2}^+$ be the state description when a handoff connection arrives at node 1, then

$$\mathbf{K}_{i2}^+ = (k_{11}, \dots, k_{N1}, k_{12} + 1, \dots, k_{N2}, k_{13}, \dots, k_{N3}) \quad (19)$$

So the dropping probability P_{hd} of handoff connections is the probability of the system in the state where a handoff connection is rejected:

$$P_{hd} = \sum_{\mathbf{K} \in \mathbf{B}_{i2}^+} \pi(\mathbf{K}) \quad (20)$$

where

$$\mathbf{B}_{i2}^+ = \{\mathbf{K} | \mathbf{K} \in \Omega, \mathbf{K}_{i2}^+ \notin \Omega\} \quad (21)$$

Let $\mathbf{K}_{i3}^*$ be the state description when an AMC mode changed connection transfers from node $i+1$ to i , then

$$\mathbf{K}_{i3}^* = (k_{11}, \dots, k_{N1}, k_{12}, \dots, k_{N2}, k_{13}, \dots, k_{(i-1)3}, k_{i3} + 1, k_{(i+1)3} - 1, \dots, k_{N3}) \quad (22)$$

An AMC mode changed connection would not be dropped when it moves from ring i to $i+1$, so the dropping probability P_{md} is the probability of the system in the state where an AMC mode connection moving from ring $i+1$ to i is rejected:

$$P_{md} = \sum_{i=1}^N \sum_{\mathbf{K} \in \mathbf{B}_{i3}^*} \pi(\mathbf{K}) \quad (23)$$

where

$$\mathbf{B}_{i3}^* = \{\mathbf{K} | \mathbf{K} \in \Omega, \mathbf{K}_{i3}^* \notin \Omega\} \quad (24)$$

V. SIMULATION RESULTS

In order to evaluate the packet-level performance of the proposed CAC scheme, we conduct a simulation program to compare it against the conventional scheme which determines the allocated resource units using the mean data rate of the connections. For the connection-level performance, the comparison algorithm does not distinguish the type of connections.

We conduct a multi-cell simulation environment of 19 cells with wrap-around mode. The radius of a cell is 1.5km. The users are uniformly distributed in the cell at the initial time of the simulation. A random walk mobility model is used with velocity of 30km/h. The system is set to work on a 10MHz bandwidth with 1024 subcarriers in which the number of data subcarriers is 720. We assume a 5ms frame and a basic allocation unit consists of 48 data subcarriers. The carrier

frequency is 2.5GHz, and the path loss model for macro cell is deployed. We divide the cell into 6 rings. The arrival of a new connection in a cell follows a Poisson distribution with the mean arrival rate λ . The arrival rate of the handoff connections will be determined by λ and the user's velocity. The lifetime of each connection is exponentially distributed with mean value $1/\mu=120$ s. In our simulation, we use the near real time video (NRTV) traffic model for variable bit rate connections with the mean bit rate $M=1.84 \times 10^5$ bps and the variance $V=8.52 \times 10^9$ bps [12].

Table 2 gives the packet-level of the proposed CAC scheme and the conventional scheme utilizing mean data rate to calculate the allocated resources. We get the maximum number of the admitted connections in one cell for the simulation environment and the associated average SNR of these connections by using the two schemes. Then we utilize the scheduling algorithm in [13] to evaluate the packet loss rate under the specific SNR and the number of users. Table 2 shows that the packet loss rate of the proposed scheme is much lower than the conventional scheme, although the latter one can admit more connections. This is because the proposed scheme takes account of the QoS requirements of the connections for the CAC criteria to guarantee the packet-level performance of the connections.

TABLE 2. THE PACKET-LEVEL PERFORMANCE COMPARISON

Average SNR (dB)	CAC Scheme	Max Number of Admitted Connections	Packet Loss Rate
10.5	Conventional	37	0.1900
	Proposed	29	0.0787
14	Conventional	50	0.1685
	Proposed	36	0.0461
18	Conventional	75	0.2768
	Proposed	40	0.0198

To evaluate the connection-level performance of the proposed scheme, we simulate the following three CAC strategies.

CAC1: The conventional CAC scheme which does not distinguish the connection type;

CAC2: The proposed CAC scheme in which the new connection does not occupy the reserved resources;

CAC3: The proposed CAC scheme in which the ratio for new connections to occupy the reserved resources $\delta > 0$.

In the simulation, we set the resource reservation coefficient $\alpha=2$ for CAC2 and CAC3, and $\delta=0.4$ for CAC3.

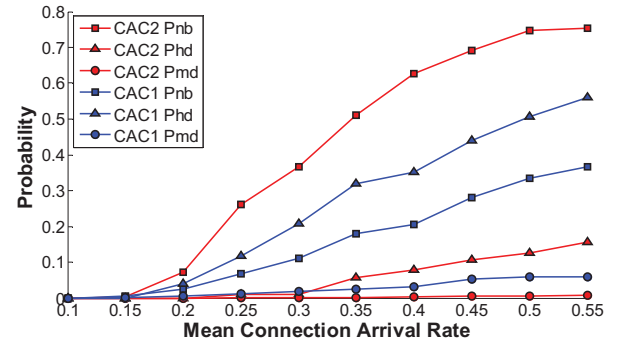


Figure 2. P_{nb} , P_{hd} and P_{md} for CAC 1 and CAC2

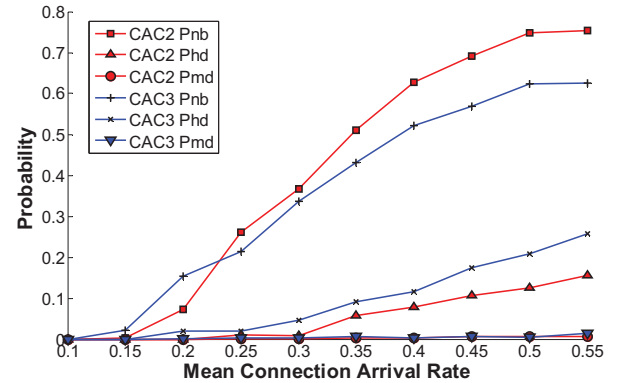


Figure 3. P_{nb} , P_{hd} and P_{md} for CAC 2 and CAC3

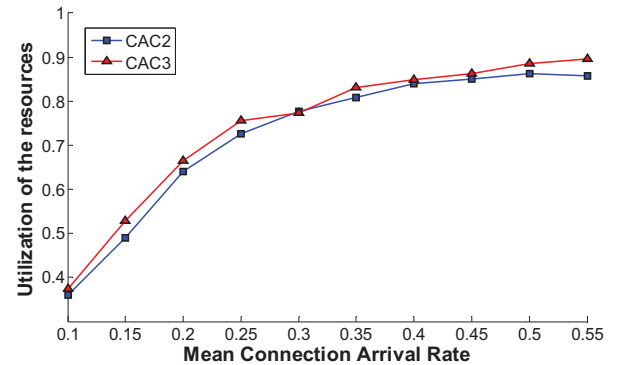


Figure 4. Utilization of the resources

Figure 2 and 3 depict the blocking probability of new connections, the dropping probability of handoff connections and AMC mode changed connections under different CAC schemes. We can see that the proposed CAC2 scheme illustrates lower dropping probability for both handoff connections and AMC changed connections which are taken precedence over new connections. For CAC1, the dropping probability of handoff connections is even higher than that of new connections, and AMC mode changed connections also get high dropping probability which is unacceptable for most ongoing connections in the network. In addition, we can notice that when sharing the reserved resources with handoff connections, AMC mode changed connections can achieve much better performance than conventional CAC scheme.

Figure 3 shows that both CAC2 and CAC3 have lower dropping probability for AMC mode changed connections. CAC3 can decrease the blocking probability for new connections for the reason that new connections can utilize some reserved resources when the available resources are sufficient. However, this leads to a little bit higher dropping probability for handoff connections.

Figure 4 compares the utilization of the system resources for CAC2 and CAC3. We define the utilization as the ratio of the admitted time-frequency resource units to total resource units. From the simulation results, CAC 3 can utilize the resources a little more efficiently because some portion of the reserved resources can be used for new connections.

VI. CONCLUSIONS

In this paper, we developed a CAC scheme for AMC-based OFDMA systems which takes into account both QoS requirements and mobility issues of the connections. We divided the cell into several rings according to the employed AMC schemes. We classify the connections into different types and use different bandwidth reservation strategies to guarantee the connection-level performance and make use of the system resources efficiently. In order to achieve packet-level performance, we determine the resource consumption based on the probability distribution of the total connections' traffics in the cell. We describe a mix BCMP queueing network with population size constraints model to analyze the connection-level performance of the proposed CAC scheme. Simulation results demonstrate the proposed scheme performs well in both packet-level and connection-level performances.

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