Call Admission Control Algorithm for IDMA System Based on SINR Evolution

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***Abstract*—Call admission control (CAC) is one of the most important issues for radio resource management of wireless communication systems, which has been widely investigated. However, the computational complexity of the CAC algorithm is still a stringent concern. The performance of interleave-division multiple-access (IDMA) system can be assessed by tracking signal-to-interference-plus-noise ratio (SINR) evolution of the iterative chip-by-chip (CBC) detection process. Based on this semi-analytical technique, a novel CAC algorithm, which makes resource estimation in advance by using the solution obtained from SINR evolution, is proposed to give a simple solution without compromising performance for CAC algorithm in IDMA systems. Besides, the effect of the base station multiuser detection (MUD) on the CAC algorithm is evaluated. It is shown that with the high efficiency of CBC MUD, a high throughput and a low blocking and dropping probability for multimedia users can be expected.**

Keywords-IDMA, mutiuser detection, call admission control, SINR evolution

I. INTRODUCTION

Interleave-division multiple-access (IDMA)[1] is a recently proposed multiple access scheme, which employs random interleavers as the only method for user separation. As a particular case of CDMA, IDMA inherits many distinguished features of well-studied CDMA. Furthermore, it allows a low-cost turbo-type multiuser detection (MUD) algorithm applicable to system with a large number of users, which is crucial for high-rate multiple access communication.

Call admission control (CAC) is one of the most important issues for radio resource management of wireless communication systems. The objective of CAC is to guarantee that the QoS of the admitted users in both the local cell and the adjacent cells will not be violated by the admission of a new user. According to our knowledge, most of the research on CAC is focused on TDMA and CDMA systems. As an newly arisen technique, IDMA has been widely investigated at physical layer, whereas the CAC algorithm, as well as other QoS guarantee techniques, is urgently desiderated to build an integrated IDMA-based next-generation wireless communication system. Besides, the computational complexity of the CAC algorithm is still a stringent concern in quasi-orthogonal CDMA system. Much research effort has been devoted to this issue in pursuit of simpler solutions without compromising performance. IDMA with a chip-by-chip (CBC) iterative multiuser detector can overcome both inter-cell and intra-cell multiple access interference (MAI) problem efficiently[2]. With the aid of the simple and efficient CBC iterative MUD in the base station, the decision of admission control is expected to be much simpler in IDMA systems. This paper is completely devoted to the investigation of call admission control issue in IDMA systems. Based on a simple semi-analytical technique, called signal-to-interference-plus-noise ratio (SINR) evolution, a novel CAC algorithm is proposed.

The rest of this paper is organized as follows. In section II, IDMA-CBC MUD algorithm and SINR evolution is illustrated respectively. And then, a novel CAC algorithm based on SINR evolution is proposed for IDMA systems in section Ⅲ. In section IV simulation results are presented. Finally, conclusions are drawn in section V.

II. MULTI-USER DETECTION AND SINR EVOLUTION IN IDMA SYSTEMS

A. IDMA-CBC MUD

Similar to Turbo decoding, IDMA-CBC MUD[3] is an iterative procedure with two decoding components, elementary signal estimator (ESE) and a posteriori probability (APP) decoder (DEC). During each iteration they exchange extrinsic informantion about $x_k(j)$ which is the output of the user dependent permutation. The CBC detection for IDMA can be concluded as follows[4]:

$$E\left(x_k(j)\right) = \tanh\left(e_{DEC}\left(x_k(j)\right)/2\right) \quad (1)$$

$$V_k(j) = Var\left(x_k(j)\right) = 1 - \left(E\left(x_k(j)\right)\right)^2 \quad (2)$$

$$E\left(\zeta_k(j)\right) = \sum_{\substack{k'=1 \\ k' \neq k}}^{K} h_{k'} E\left(x_{k'}(j)\right) \quad (3)$$

$$Var\left(\zeta_k(j)\right) = \sum_{\substack{k'=1 \\ k' \neq k}}^{K} \left|h_{k'}\right|^2 Var\left(x_{k'}(j)\right) + \sigma^2 \quad (4)$$

$$e_{ESE}\left(x_k(j)\right) = 2h_k \cdot \frac{r(j) - E\left(\zeta_k(j)\right)}{Var\left(\zeta_k(j)\right)}, \quad \forall k, j \quad (5)$$

where $\zeta_k(j)$ is the distortion contained in $r(j)$ with

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respect to user-k, h_k is the channel coefficient for user-k. DEC$_k$ generates $\{e_{DEC}(x_k(j)), \forall k, j\}$, which are used to update mean and variance of $\{x_k(j)\}$ [5].

B. Semi-analytical performance evaluation method based on SINR evolution

The performance analysis for a conventional CDMA MUD scheme requires the knowledge of the correlation characteristics among signature sequences. It is a quite complicated issue and the sophisticated large random matrix theory has been adopted in the past to tackle the problem. However, IDMA does not involve signature sequences, which greatly simplifies the problem. On this basis, a simple and efficient performance assessment technique is derived as follows[1][5]. This method is semi-analytical since some of the funtions involved are pre-calculated by simulation.

The performance of IDMA-CBC MUD depends on the amount of cancelled MAI, equivalently, the amount of variance reduced from the $\{x_k(j), \forall k, j\}$ variables[5]. For each iteration, this variance reduction is obtained in the ESE by using all extrinsic variable $\{e_{DEC}(x_k(j)), \forall k, j\}$.

For large K, simulation obervations and analysis reveal that upon iteration convergence, $e_{DEC}(x_k(j))$ is approximated to a Gaussian random variable. The Gaussian mean and variance depend on the encoder and the decoder structure. The SINR evolution here concerns with the decoder performance at the iteration convergence point, where

$$V_k(j) \approx V_k = 1 - \tanh^2\left(\frac{Y_{\gamma_k}}{2}\right), k = 1, ..., K \qquad (6)$$

and Y_{γ_k} is a Gaussian random variable whose mean and variance are determined by the SINR of the chip signal, γ_k, at the convergence point. As shown in Eqs. (6) , V_k is independent with j, since all data symbols are assumed to be independent and identically distributed.

Suppose that for each user-k, a fixed received power, S_k can be maintained under the ideal power control which aims at achieving the SINR targets upon iteration convergence when MAI interference is maximally cancelled. Consequently, the following constraint must be applied at the iteration convergence:

$$\frac{S_k}{\sigma^2 + \sum_{i \neq k} S_i \cdot f(\gamma_i)} \geq \gamma_k, \qquad k = 1, ..., K \qquad (7)$$

where σ^2 is the power spectral density of the AWGN background noise and

$$f(\gamma_k) = 1 - E\left[\tanh^2\left(\frac{Y_{\gamma k}}{2}\right)\right], \qquad k = 1, ..., K \qquad (8)$$

The function $f(\gamma_k)$ reflects the interference cancellation resulting from the iterative turbo decoder. It takes value in (0, 1), and is strictly decreasing and convex.

Generally, $f(\gamma_k)$ does not have an analytical expression and is derived by simulation. For BPSK with repetition-code (each bit is replicated N times over the symbol chips), it can be shown that for large J, where chip MAI is approximately Gaussian, Y_{γ_k}, is also approximately Gaussian with mean and variance $2(N-1)\gamma_k$ and $4(N-1)\gamma_k$, respectively[5]. The funtion is depicted in Fig. 1.

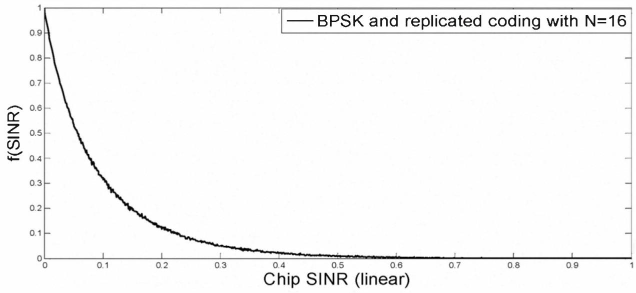

Fig. 1. $f(\gamma)$ vs. chip level SINR

When all users receive the same power, i.e., $S_k \equiv S, \forall k$, and all users can meet the SINR requirements, i.e. , $\gamma_k = \gamma, \forall k$, is of particular interest for the power control problem. For this case, by $f(\gamma_k)$, the SINR target is

$$\gamma = \frac{S}{\sigma^2 + (K-1) \cdot S \cdot f(\gamma)}. \qquad (9)$$

III. CAC Algorithm for IDMA System Based on SINR Evolution

In this part, we focus on the CAC algorithm for IDMA systems with multiple types of services requiring different SINR and transmission rates. The required SINR varies with call classes, which is directly related to the total interference in the system. Considering the performance of IDMA systems is mainly limited by the interference among the users[6], the call admission decision in the proposed algorithm is based on total interference measurement. A call is admitted if the interference level is below a certain level that guarantees the communication quality. In addition, the proposed algorithm guarantees the priority of handoff call requests over new call requests.

With the aid of this SINR evolution technique developed from the IDMA systems, the complicated computation of intensive sophisticated large random matrix in making every call admission decision can be avoided, which is necessary in CDMA systems. The uncancelled percentage of the intra-cell interference is referred here as the efficiency of the multiuser detection $f(\gamma)$ function.

A. Estimation of System Interference Increasing

In a cellular IDMA system the same pair of frequency bands are reused for each cell. Thus, each base station not only receives interference from mobiles in the home cell (intra-cell interference) but also from terminals located in adjacent cells (inter-cell interference)[7]. The total interference I_{total} in a home cell without MUD is

$$I_{total} = I_{intra} + I_{inter} + P_N \quad (10)$$

with

I_{intra} : The intra-cell interference from users in home cell.

I_{inter} : Received power from adjacent cells in home cell.

P_N : The thermal background noise $P_N = N_0 W$.

Traditionally, the total interference contributed by a cell has been viewed as an approximation, determined by simply multiplying the number of users in that cell by the average per-user inter-cell interference factor offered by that cell[8]. f is defined as the ratio of the total interference power from adjacent cells (I_{inter}) and the interference power generated by users in the home cell (I_{intra}), which can be written as

$$f = I_{inter} / I_{intra} \quad (11)$$

If the average interference is used, the average ratio f can be considered as a constant 0.48, which is found analytically for the situation without shadowing and is comfirmed by results presented in [8]. From (10) it follows that the total interference received in the home cell is

$$I_{total} = I_{intra} + f \cdot I_{intra} + P_N \quad (12)$$

Required SINR$_k$ for service type k assumed to be γ_k under perfect power control can be written as

$$\gamma_k = \left(\frac{E_b}{I_0} \right)_k = \frac{S_k}{I_{total}} \cdot \frac{W}{\left(R_k \cdot \alpha_k \right)} \quad (13)$$

where α_k and S_k are the activity factors and required transmission power of an active mobile of traffic type k=c(CBR), v(VBR) and u(UBR) respectively. Define the load factor of a single connection as

$$L_k = \frac{1}{1 + \frac{W}{\gamma_k R_k \alpha_k}} \quad . \quad (14)$$

Then the received power S_k and the total intra-cell interference power from users in home cell can be writen as

$$S_k = L_k \cdot I_{total} \quad (15)$$

and

$$I_{intra} = \sum_{k=1}^{N} L_k \cdot I_{total} \cdot N_k \quad (16)$$

where N and N_k is the types of different services and amount of users corresponding to service type k. Similarly, we define the fractional load factor in the home cell η as

$$\eta = (1+f) \sum_{k=1}^{N} L_k \cdot N_k \ , \quad (17)$$

which is normally used as the home cell load indicator. Based on (17) , the total interference received in the home cell without MUD can be written as

$$I_{total} = \eta \cdot I_{total} + P_N \quad (18)$$

and

$$I_{total} = \frac{P_N}{1-\eta} \ . \quad (19)$$

The interference power I_{total} increases when the fractional load factor η increases.

The effect of CBC MUD to the system performance is taken into account by cancelling part of the intra-cell interference. Based on the semi-analytical SINR evolution proposed in the section II, by (10), the total interference and fractional load in the home cell can be derived as

$$I_{total} = f(\gamma) \cdot I_{intra} + f \cdot I_{intra} + P_N \quad (20)$$

and

$$\eta = (f(\gamma) + f) \sum_{k=1}^{N} L_k \cdot N_k \quad (21)$$

where $f(\gamma)$ is the remained percentage of inra-cell interference.

With the aid of detivative form of Eqs. (19) , the increase of the total interference level due to a new requiring user can be estimated as follows:

$$\Delta I = \frac{I_{total}}{1-\eta-\Delta L} \Delta L \quad (22)$$

where

$$\Delta L = \frac{1}{1 + \frac{W}{\gamma R \alpha}} \quad (23)$$

is the load factor of the user requesting to be admitted into the radio access network.

Similarly, from Eqs. (20)-(22) the interference increase with CBC MUD in IDMA systems is simply estimated as follows

$$\Delta I = \frac{I_{total} \cdot \left(f + f(\gamma_k) \right)}{1 - \eta - \left(f + f(\gamma_k) \right) \cdot \Delta L} \Delta L \quad (24)$$

An upper bound on the capacity increase is easily derived by comparing the total interference for systems with and without MUD. For an IDMA system with ideal CBC MUD where the total interference is left with $I_{total} = \left(f(\gamma) + f \right) \cdot I_{intra} + P_N$, compared to the total interference in the system without MUD. Since the number of users is roughly proportional to the total interference, capacity gain factor in IDMA systems would be $\left(f(\gamma)+f\right)/f$. A typical value for f in cellular systems is 0.48[8], leading to a maximum capacity gain factor of 3.1.

B. Call admission algorithm

The proposed call admission algorithm is explained in Fig. 2, where I_{total} is the current total received power at the home cell base station, and ΔI is the increasing interference due to a new user.

When a new call request arrives, it will be accepted if

$$I_{total} + \Delta I \le I_{THRESHOLD} \tag{25}$$

is satisfied, otherwise CAC is executed according to its type. Similarly, if a handoff call arrives, the CAC algorithm decides whether to admitted the call according to the result of

$$I_{total} + \Delta I \le I_{threshold} \tag{26}$$

In the proposed CAC algorithm, handoff requests have higher priority over new calls of the same class. This is supported by setting $I_{threshold} > I_{THRESHOLD}$ [9].

It is a very simple policy easily to be implemented, provided that the total interference and the increasing interference can be estimated simultaneously by (20) and (24). By avoiding the complicated computation of intensive sophisticated large random matrix in making every call admission decision, the CAC algorithm based on the SINR evolution has the $O(1)$ computational complexity. After one call leaves, it refresh the system parameter according to the traffic type.

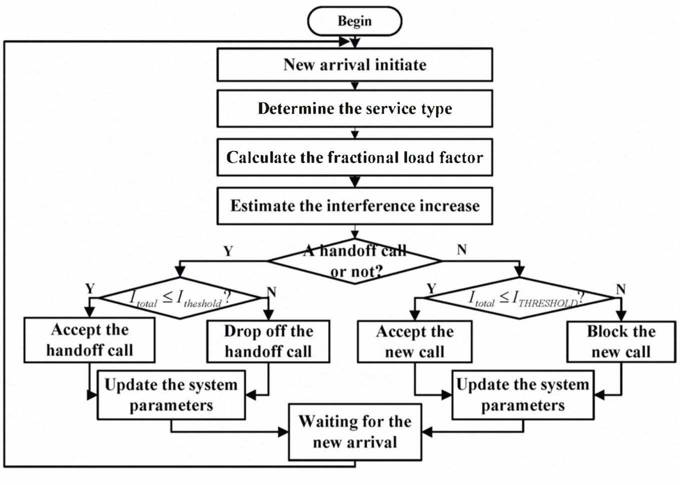

Fig. 2. Flowchart of the proposed IDMA CAC algorithm

IV. EXPERIMENT RESULTS

In this section, experimental results are presented to demontrate the performance of the proposed CAC algorithm for IDMA systems.

Considering the ideal hexagon cell system, the home cell is surrounded by other eighteen cells, shown in Fig. 3. Only the inter-cell interference from these eighteen cells is considered. For each cell there are three kinds of traffic. All of them share the same bandwidth of 5MHz and the thermal power spectral density of the AWGN background noise of -169dBm • Hz^{-1}. Based on the multimedia traffic requirements and the 3GPP specification, we define traffic QoS as shown in Table. I [10]. A call request of each service arrives at BS according to Possion process, and the arrival process of different traffic is independent. The arrival interval and the serving time are distributed exponentially. The average serving time of the service is 100s. A new call is randomly determined as Voice ,Video and Background date with probability 40%, 30% and 30%, respctively.

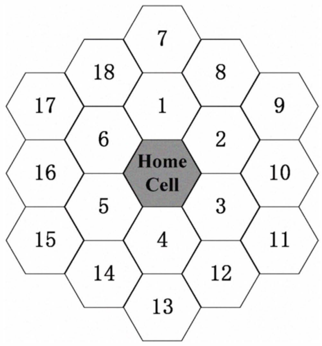

Fig.3. The cell layout for simulation

1) Voice traffic is a Constant Bit Rate (CBR) under an ON/OFF activity model, and the active factor is α_c . During the active time interval, the transmission rate of voice is the desired rate R_c bps, while it is 0 during the idle time interval.

2) Video traffic is a Variable Bit Rate (VBR) model, simulated by a decrete-state continous time Markov process.

3) Background traffic follows self-similar process modeled as the Pareto process. It is an Unspecified Bit Rate (UBR) traffic[10].

TABLE I. PARADIGM OF SERVICE CLASS

Service	Service Class	Desired Rate (kbit/s)	SNR (dB)	Active Factor
Voice	Premium	12.2	6	0.6
Video	Assured	32	7	1.0
Background date	Best Effort	64	10	0.1

Fig. 4 shows the process of CAC for 100 calls during a simulation, from which the class of the user, the arrival time and whether the new call or handoff call is accepted or not can be clearly seen. For simplicity, we number the different classes respectively.

Due to the high efficiency of CBC MUD, much of the inra-cell interference can be cancelled. This can be explained by the f function (see Fig. 1). Since IDMA capacity is interference limited, any reduction in interference converts directly and linearly into an increase in capacity. It can be seen from Fig. 5, the fractional load keeps high all the time, leading to a high throughput consequently, shown in Fig. 6. Here, throughput is the average data rate served to each accepted user and calculated as the total served bit rate divided by total accepted calls.

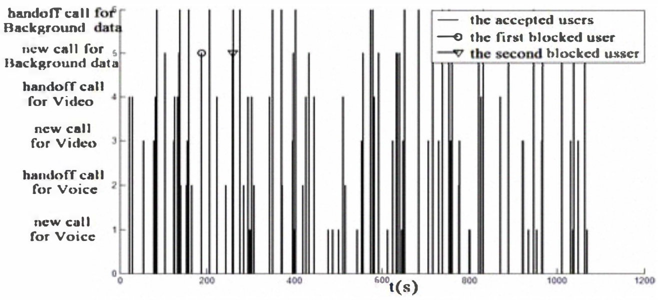

Fig. 4. The process of CAC for one simulation

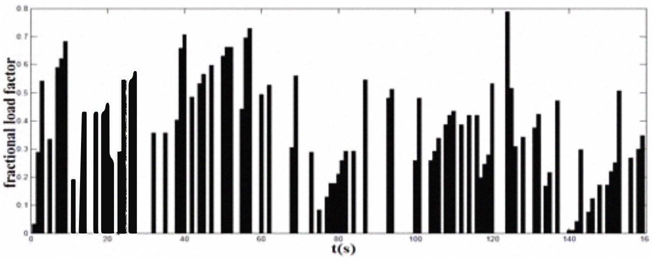

Fig. 5. The fractional load factor for one simulation

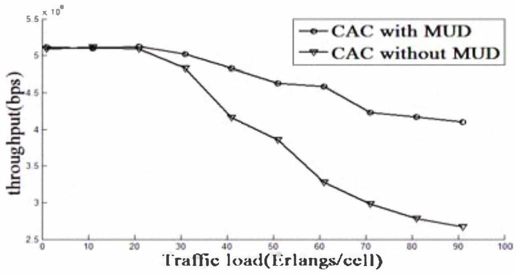

Fig. 6. Performance comparison of throughput with and without MUD

For comparison, the performances of the blocking and dropping probability considering the effects of MUD are shown in Fig. 7 and Fig. 8 respectively. The lower blocking and dropping probability can be obtained in cases with MUD and the dropping probability is approximated to zero even at higher load.

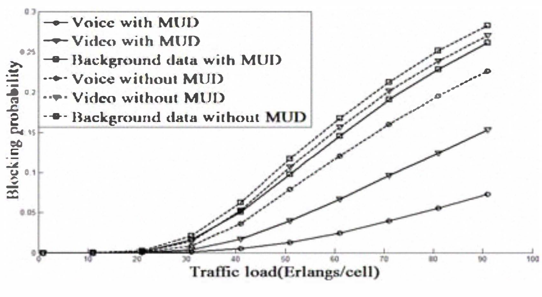

Fig. 7 . Averaged blocking probablity for different services in IDMA systems with and without MUD

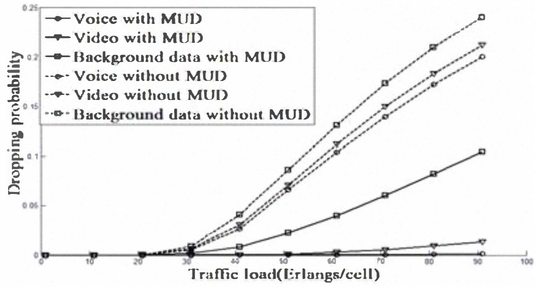

Fig. 8. Averaged dropping probablity for different services in IDMA system with and without MUD

It is indicated that the proposed CAC algorithm in IDMA systems could give better performance by virtue of the effect of the CBC MUD.

V. CONCLUSIONS

Based on the fast and relatively accurate semi-analytical technique developed from IDMA systems, a novel CAC algorithm is proposed in this paper. With the aid of the SINR evolution technique, the complicated computation of intensive sophisticated large random matrix in making every call admission decision, which is necessary in CDMA systems, can be avoided in the base station. Also, thanks to the high efficiency of the station MUD, the performance of the interference based admission control can be further improved, and consequently a larger number of simultaneous users can be supported.

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