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Multi-User Resource Allocation for Downlink Multi-Cluster Multicarrier DS CDMA System

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Abstract: In this paper, we consider an adaptive multi-user resource allocation for the downlink transmission of a multi cluster tactical multicarrier DS CDMA network. The goal is to maximize the sum packet throughput, subject to transmit power constraints. Since the objective function turns out to be noncovex and non differentiable, we propose a simple iterative bisection algorithm. At each iteration, a closed-form expression is derived for the transmit power, sub channel, and modulation assignment, which significantly reduces the computational complexity. We also provide an optimization algorithm for the downlink transmission under the condition of imperfect channel knowledge, and investigate the effects of both channel estimation error and partial-band jamming.

Keywords: CDMA, Downlink, Multi-User Resource Allocation, Channel Estimation Error, Jamming.

I. INTRODUCTION

Often, power control is mainly used to eliminate the near-far effect and reduce co channel interference to guarantee a minimum SINR threshold [2], [3]. In the future generations of wireless networks, we expect that adaptive resource allocation (ARA) will be modeled as a network utility maximization problem. In general, authors formulate the utility function of each user as a nonlinear, convex function of SINR, and log-type utility functions are the most widely used in the literature. The concavity property of these utility functions plays a key role in the development of optimal resource allocation strategies [4]-[6]. However, the concavity condition of the utility function of SINR is too restrictive, and non-concave utility functions are more appropriate in many cases [7]-[11]. The sigmoid utility function has been used in [7], [8]. In [9], the sigmoid utility function with pricing is considered, and the paper shows that the algorithm is more flexible because of the pricing. Ref. [10] develops a simple downlink ARA algorithm with three types of utility functions (concave, convex, and sigmoid like). However, it only considers a single channel without adaptive modulation. In [11], a set of sufficient and necessary conditions for global convergence of the canonical distributed algorithm is presented.

However, certain properties of above approximate utility functions, such as the continuous data rate and infinite alphabet size (or single alphabet size), are unrealistic in a practical system, and lead to an over-simplification of the optimization problem. For a practical system, packet throughput is often considered as the utility function [11]-[12]. In [12], considering the packet throughput with a certain modulation, a power-control algorithm is proposed for a single-cell system. In [12], a greedy algorithm is proposed to maximize the total packet throughput in a single-user multicarrier system. Ref. [12] studies the effect of modulation on energy efficiency in multi-user CDMA networks for single channel case using a game-theoretic approach.

In this work, we investigate the ARA for a multi-user and multi-cluster tactical multicarrier (MC) DS CDMA system. Focusing on the downlink transmission, we propose a simple iterative bisection algorithm to optimally allocate the transmit power, available sub channels and modulation alphabet size; so that the sum packet throughput is maximized with transmit power constraints. In order to reduce the computational complexity, in each iteration, we provide a mathematical expression for the transmit power, sub channel and modulation assignment. Also, we investigate the effects of channel estimation error and partial-band jamming on the ARA in a tactical MC DS CDMA network.

The remainder of this paper is organized as follows. Multirate CDMA Network is given in Section II. Adaptive Modulation for CDMA Network in Section III, and numerical results and conclusions are given in Section IV and V respectively.

II. MULTIRATE CDMA NETWORK

Increase in demands for multimedia services has led to an increase in need for different data rate services. The bit rate requirement may vary from a few kbps to as much as 2 Mbps. Proposed a non co-operative game for multi rate CDMA system. Multi rate CDMA system can be designed in many ways.

The scheme used in this paper is variable spreading gain access. For a single cell CDMA system with N active terminals, each user transmits its signals at different rates. However all users have the same chip rate, hence the signals are spread to the same bandwidth. In the Power Control Game (PCG), the users are regarded as players of the game. Each player has a pay-off function. The payoff of the player is its throughput. Hence this game is called throughput maximization game (TMG). Also in order to improve the performance of the system, a new pricing function mechanism is introduced. This is used in order to prevent the interference among the users. Whenever a user's transmission causes interference to the transmission of other users, a price is charged for creating interference. This pricing function is the ratio of the normalized received power to the total received power plus noise at the base station. Then a new payoff function is defined for each player by subtracting this new pricing function from the payoff considered without pricing. This new game is called Throughput maximization game with pricing (TMGP). The spectral efficiency (total throughput per bandwidth) for Binary Input Gaussian Output (BIGO) channel and Binary Symmetric Channel (BSC) channel are derived and analyzed. This analysis is performed in terms of ratio of energy per bit to interference spectral density (Eb/Jo) and spectral efficiency η.

TABLE: 1
SPECTRAL EFFICIENCY FOR BIGO AND BSC CHANNELS

E_b/J_o	Spectral efficiency	
	BIGO	BSC
0	1.40	0.90
2	0.45	0.42
4	0.25	0.25
6	0.15	0.17

From the Table 1, it is seen that the spectral efficiency is a decreasing function of Eb/Jo. The maximum spectral efficiency is achieved when Eb/Jo is zero for both types of channels. Also the spectral efficiency achieved for BIGO channel is higher than that achieved for BSC channel for any value of Eb/Jo.

In this paper, it is also proved that multi rate CDMA system with a given rate vector can achieve the same spectral efficiency as a single rate CDMA system. With the introduced pricing, the game is shown to possess unique Nash equilibrium. This equilibrium maximizes the total throughput over a hyper plane with fixed total power.

A. Subcarrier and Power Allocation for OFDMA Network

It proposed a joint sub carrier and power allocation method for the uplink of the OFDMA system. The uplink of an OFDMA transmission system with K users and N subcarriers is considered. The system is assumed to be synchronized and so it is almost free from multi-user interference (MUI). Here, the resource allocation strategy is formulated with the aim of maximizing the total utility of the users. The utility of the users is a function of the user's throughput. The total available subcarriers are assigned one by one to the users sequentially. Whenever a subcarrier is assigned, all users update their power allocation. Then another subcarrier is assigned. This process of allocating the subcarrier and power simultaneously continues until all the available subcarriers are assigned. Each user is allocated sub carrier uniquely and hence the power allocation of the users is independent of each other. This is done by maximizing the utility function which is equivalent to maximizing the throughput.

The optimal power allocation is water filling over all the subcarriers and the water filling solution is given as follows:

$$p_{i,j} = x_{i,j}\left[v_i - \frac{1}{g_{i,j}}\right]^+ \qquad (1)$$

Where $p_{i,j}$ is the power allocated to subcarrier j by user i, $x_{i,j}$ is the binary decision variable of subcarrier allocation, $g_{i,j}$ is the ratio of the channel gain to noise power of subcarrier j of user i, and $x + = \max\{0, x\}$, vi is a constant which is commonly called the water level of user I such that

$$\sum_{j=1}^{N} p_{i,j} = P_i \qquad (2)$$

Where N represents the number of subcarriers and Pi is the total power of user i.

The Base Station (BS) executes the subcarrier and power allocation algorithm shown in Fig 1 to allocate the subcarrier and power for each user. The subcarrier allocation strategy may possibly be throughput optimization, proportional fairness or max-min fairness. This algorithm has a time complexity of O (KN log2N), where K, N denotes the number of users and subcarriers respectively. The solution obtained by this method is shown to be paring to optimal within a very large neighborhood.

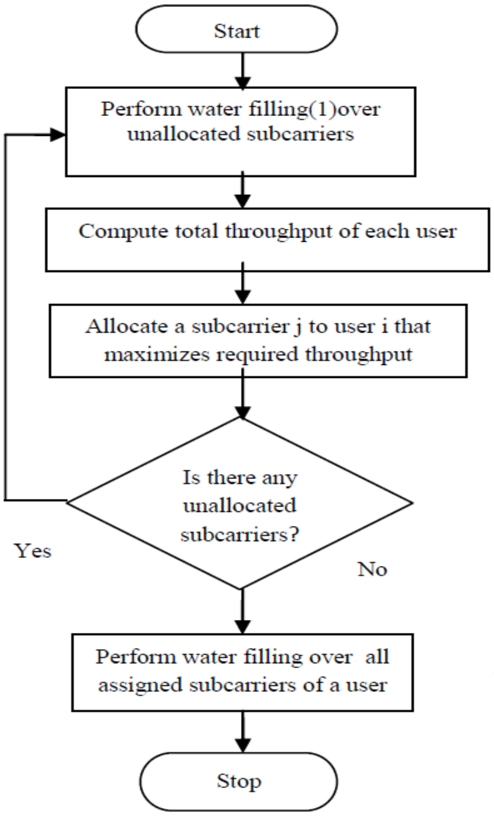

Fig.1. Flow diagram for subcarriers and power allocation

The throughput of the users increases with an increase in the number of subcarriers. Also as the number of users increases, the throughput further increases. The performance of this algorithm is close to that of the optimal solution.

III. ADAPTIVE MODULATION FOR CDMA NETWORK

Adaptive modulation improves the spectral efficiency in wireless networks, studied the effect of constellation size on energy efficiency of wireless networks using a game theoretic approach. This is posed as a non-cooperative game in which the users are allowed to choose their transmit power, symbol rate and modulation size with the aim of maximizing the utility function. The utility function defined here is the ratio of the throughput to the transmit power. For a user k, the utility function is given by

$$u_k = \frac{T_k}{p_k} \tag{3}$$

Where u_k is its utility function, T_k is the throughput and p_k is the transmit power of user k.

For the utility function given in (3), the best strategy is to transmit the symbols with the lowest order modulation. Also it is implied that being energy efficient is not spectrally efficient. If a user switches to a higher order modulation from a lower order one for the same bandwidth and symbol rate, the spectral efficiency increase at the cost of energy efficiency. When the system has an additional delay QoS constraint, the same game is slightly modified in which each player maximizes its own utility in addition to satisfying the delay QoS constraint. This delay includes both transmission and queuing delays. For this case also it is shown that to maximize the energy efficiency, the user must always choose the lowest order modulation for which the delay constraint is satisfied. The solution obtained by this method is proved to possess Nash Equilibrium. The effect of Trellis coded modulation (TCM) on energy efficiency is analyzed using the game theoretic approach. A comparative analysis of energy efficiency and signal to interference ratio (SIR) obtained for coded and un coded schemes for different modulation size is given in the following table.

TABLE: 2
COMPARISON OF CODED AND UN CODED SYSTEMS

Modulation Size	Uncoded Systems		Coded Systems	
	SIR	Energy Efficiency	SIR	Energy Efficiency
2	9.1	0.19	8.1	0.29
4	15.7	0.08	14.2	0.13
6	21.6	0.03	20.4	0.04
8	27.3	0.01	26.3	0.16

From Table 2, it is found that with coding scheme, the signal to interference ratio is decreased relative to that of the un-coded scheme but however the energy efficiency of the users is increased considerably. Also, it is seen that higher energy efficiency is achieved for lower order modulation compared to that of the higher order modulation.

A. Resource Allocation for OFDMA Network with Imperfect CSI

It proposed a scheme for allocation of subcarrier, rates and power in OFDMA network. The OFDMA systems transmit the wideband signal as multiple narrowband signals over sub bands that are supported by subcarriers and with a bandwidth that is less than the channel coherence bandwidth. The main focus is to allocate network resources with imperfect channel state information (CSI), and for multiple classes of service that demands diverse QoS requirements.

This proposed system works for a Point to Multipoint (PMP) network with a single Base Station (BS) to support multiple subscriber stations. The BS performs the resource allocation for all its subscriber station. The BS has two layers: Physical (PHY) and Medium Access Control (MAC) layer. The Resource Allocation Unit (RAU) and Call Admission Control (CAC) unit are present within the MAC layer. The physical layer is responsible for feeding the CSI of all subcarriers to the RAU. The RAU in turn allocates the resources to all subscribers. The CSI is updated every OFDMA frame. Based on the CSI, the resources allocation process is updated. The CAC unit receives the resource allocation results from RAU and updates it based on network requirements. The resource allocation is modeled as constrained Network Utility Maximization (NUM) problem, with the objective of maximizing the subscribers' utility functions. The constraints are network specific. The authors considered the constraints to be per-service aggregate rate limit, power limitation and exclusive subcarrier allocation. The exclusive subcarrier assignment constraint results in non convex feasible space. Hence it is solved in dual domain by decomposition of the dual problem into a hierarchy of sub problems that are solved easily than the primal. This hierarchical decomposition of the problem is shown in Fig 2.

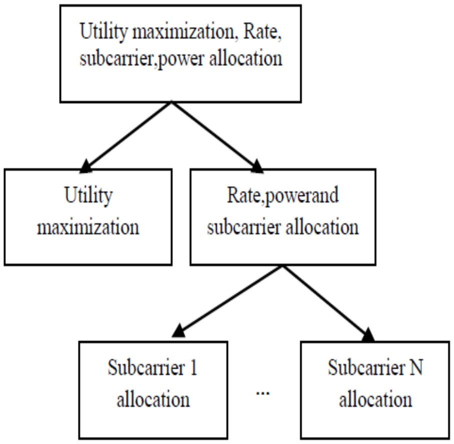

Fig.2. Hierarchy of dual problem decomposition

The master dual problem sets prices for resources and reports them to decomposed sub problems. This master dual problem represents utility maximization, subcarrier, rates and power allocation. This is decomposed into two sub problems: (1) Utility maximization and (2) Subcarrier, Power, Rate allocation. The second sub problem is complicated to solve, hence is again decomposed into a number of sub problems. This number equals the number of sub carriers. Then each of these sub problems is solved coordinated by the master dual problem. In the Fig. 2, the topmost box represents the master dual problem that is in turn decomposed into sub problems. A subcarrier is exclusively allocated to the particular subscriber that maximizes the following equation:

$$\arg\max_s \delta^s E[r_n^s] - \nu p_n^s, \quad \forall n \tag{4}$$

Where $E[r_n^s]$ is the expected rate and p_n^s represents the required power to support the expected rate, δ^s represents the rate allocation for the *sth* subscriber. This scheme has low computation complexity due to dual decomposition approach. Also, this resource allocation scheme maintains the aggregate rate limit for each service class in a multiservice class network. The expected rate achieved by a subscriber increases as the power to noise ratio increases. Also, this rate is highest when the RAU has perfect knowledge of the CSI. In case of imperfect CSI, the expected rate achieved decreases depending on the amount of the channel estimation error.

B. Adaptive Resource Allocation for Distributed Network

Adaptive resource allocation for a distributed multi carrier DS-CDMA networks is proposed it considered the resource allocation process in a distributed fashion where each user allocates his/her resources based on the condition of the channel while satisfying its own requirements without requiring the use of a central coordinator to coordinate resource allocation. A distributed network with users randomly deployed within a given region is considered. A transmitter and a receiver communicate with each other and form one to one communication pair.

In this paper a suboptimal non-cooperative game is proposed to adaptively allocate the transmit power, available sub channels and alphabet size. Each user present in the network has a maximum power constraint and packet throughput requirement. The users optimally choose the resources necessary for transmission satisfying the required constraints. This resource allocation problem is solved in dual domain. For this, a bisection algorithm is proposed that adaptively allocates the resources to each user. In each time slot, the transmitters employ this algorithm simultaneously. Then the receivers estimate the CSI and feeds back to the corresponding transmitters for updating its local signal to interference plus noise ratio (SINR) periodically. Since the transmission spectrum and power profile of users change, the SINR at the channel may be different during each time slot. Thus the bisection algorithm is used iteratively by the users to adjust the available sub channels, transmit power allocation and modulation size to satisfy the throughput requirement and transmit power constraint. If the constraints are satisfied, then the users transmit with allocated resources, otherwise the users stop transmission. Also the effect of imperfect CSI on adaptive resource allocation process is analyzed and found that the performance of this algorithm is better than equal power allocation scheme when the channel estimation error ratio (CEER) is small. But as the CEER increases, the performance degradation is observed compared to that of equal power allocation scheme.

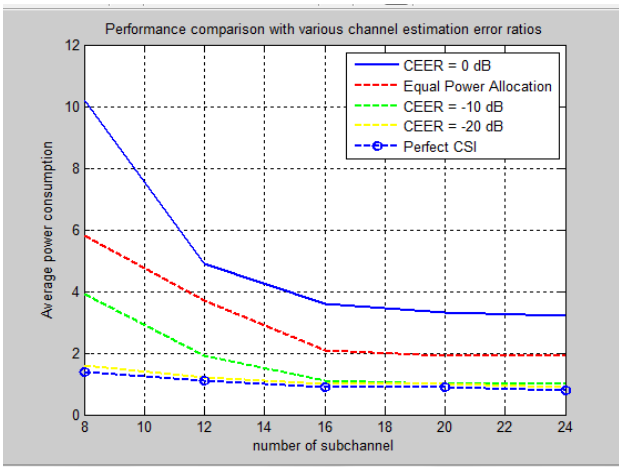

Fig.3. Performance analyses with various channel estimation errors.

Fig. 3 shows the effect of available sub channels on average power consumption for various CEERs. It is seen that as the number of available sub channels increases, the average power consumption decreases. Also, from the above result, it is inferred that the power consumption is small when the channel estimation errors are small. As the channel estimation error increases, the average power consumption increases, and becomes higher than that of equal power allocation when CEER is 0dB. From these results, it is concluded that this adaptive resource allocation algorithm works well when the channel estimation error ratio (CEER) is small.

IV. NUMERICAL RESULTS

In this section, we provide numerical results to illustrate the performance of the proposed iterative bisection algorithm. We choose 4-QAM, 16-QAM and 64-QAM as the allowable modulation formats. In Fig. 4, in order to show the accuracy of the proposed algorithm, we compare the performance of the proposed iterative bisection algorithm with the global optimization using an exhaustive search. The total power constraint is set to be 10, the number of symbols each packet L= 100, the number of sub channels N =4, and the number of users is taken to be either K =10 or K =15. It is seen that the performance of the proposed algorithm is almost the same as that of the global optimization, which indicates that the duality gap of the dual optimization problem is very small. We know that the duality gap of the dual optimization problem decreases when either K or N increases [9]. So, it is reasonable for us to use the proposed iterative bisection algorithm to solve the ARA problem.

The effect of the channel estimation error on system performance is illustrated in Fig. 5, where the curves are parameterized by the channel estimation error ratio $\rho_{k,n}$. The number of users K = 10, and the number of available sub channels N = 4. When $\rho_{k,n}$ is small (e.g., $\rho_{k,n} = -30dB$), the effect of the channel estimation error is less significant than that of the background noise, so that the performance under imperfect CSI is comparable to that with perfect CSI. We also show the performance of the equal power allocation (EPA) with 4-QAM, 16-QAM or 64-QAM. The result shows that when the estimation error ratio is small (e.g., $\rho_{k,n}$ = $-20dB$ or $-30dB$), the performance under imperfect CSI is better than that of the EPA. When the estimation error ratio is large (e.g., $\rho_{k,n}$ = $0dB$), the performance of the ARA is worse than that of EPA, which means that we should not use the ARA in this situation. It also can be seen that there are crossover points for the performances of EPA. This is because, in the low SINR region, a small size alphabet provides higher packet throughput, while a large size alphabet in the high SINR region has a higher packet throughput.

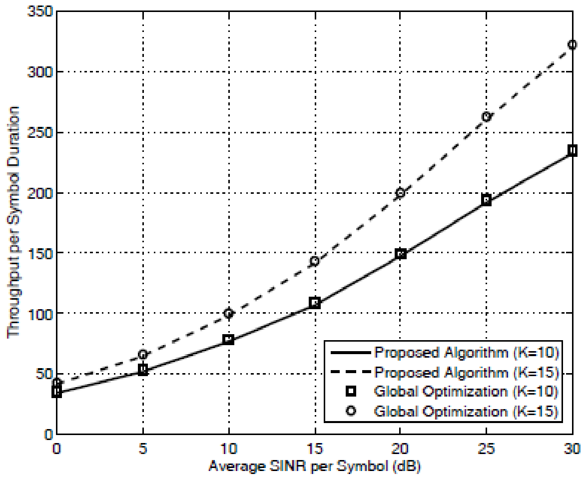

Fig.4. Performance comparison of the proposed algorithm and global optimization

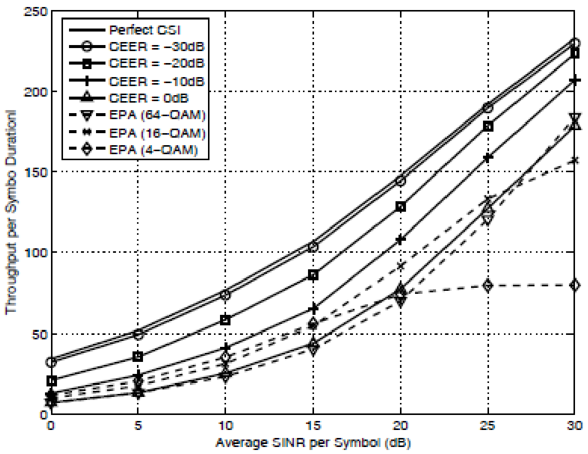

Fig.5. Comparison of ARA and EPA with various estimation error ratios.

We investigate the effect of coherence time T_{Co} and pilot SINR on system performance in Fig. 6. The average SINR is set to be 10*dB*, the number of users $K = 10$, and the number of available sub channels $N = 4$. It is seen that the performance becomes better as either T_{Co} or pilot SINR increases, and it is more sensitive when either T_{Co} or pilot SINR decreases. When T_{Co}/T_S is large (e.g., $T_{Co}/T_S = 100$), i.e., the system experiences slow fading, the performance of the ARA under imperfect CSI provides comparable performance to that with perfect CSI, even when the pilot SINR is low. Therefore, we expect to use the ARA in a slow fading system.

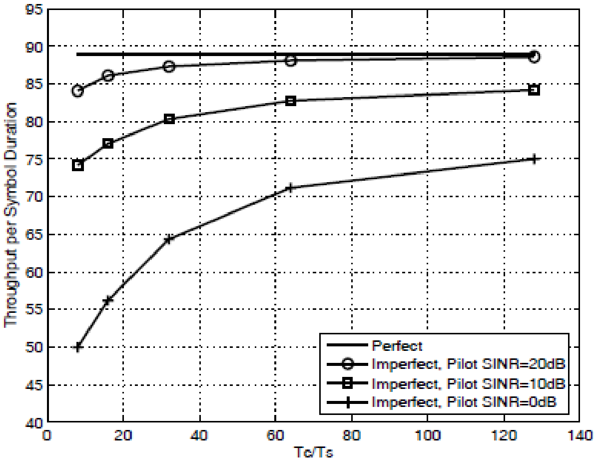

Fig.6. Performance comparison with various coherence times and pilot SINRs.

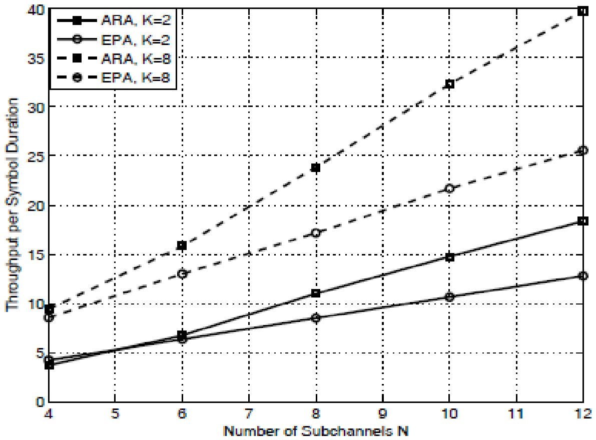

Fig.7. Performance comparison with various numbers of available sub-channels.

Fig. 7 shows the effects of the number of users and the number of available sub channels on the system performance. We assume the total jamming power is constant. When $N = 4$, we set the average SINR= 5*dB*, and the estimation error ratio to be −5*dB*. It is seen that the performance becomes better as the number of users and available sub channels increase. When $N = 4$ and $K = 2$, the performance of the ARA is worse than that of the EPA. When either K or N increases, the performances of the ARA become better than that of EPA. This is reasonable because, with N increasing, the probability of different users using the same sub channel will decrease, which leads to smaller average co-channel interference per Sub channel. Also, when the number of users and available Sub channels increase, it is more likely to allocate the transmit power to users with good channel conditions. Thus, a larger number of users and sub channels can improve the performance of the ARA.

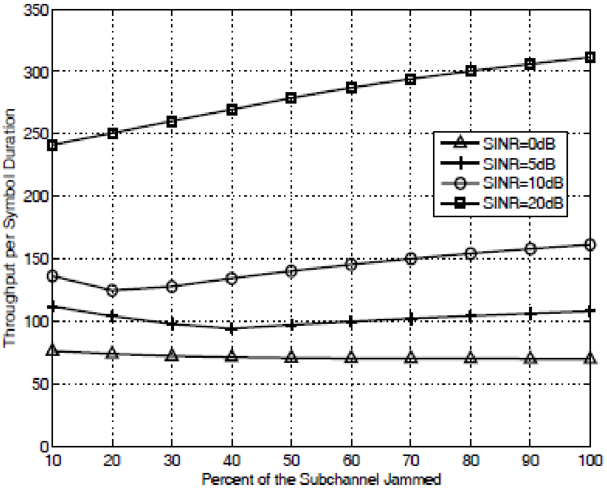

Fig.8. Performance comparison of full-band and partial-band jamming.

Fig. 8 investigates the effect of partial-band jamming on the system performance. We set the number of users $K = 10$, the number of available sub channels $N = 10$, and the ratio of the total jamming power to the interference and noise power in all N sub channels to be 10. We simulate the performances under full-band jamming with various SINR, and compare them to the performance under partial-band jamming. It is seen that the partial-band jamming can degrade the system performance over full-band jamming, especially for high SINR region. The jamming percentage of sub channels for the worst case jamming strategy decreases as the SINR increases, and low SINR (e.g., SINR=0*dB*) leads to full-band jamming. This is because, when SINR is small, the jammer has enough power to cause all the available sub channels to have high packet error rate.

V. CONCLUSIONS

We have studied an adaptive multi-user resource allocation for the downlink transmission of a MS DS CDMA network. We proposed a simple iterative bisection algorithm to adaptively allocate the transmit power, available sub channels and alphabet size by maximizing the sum packet throughput with transmit power constraints. Also, we investigated the effect of channel estimation error and partial-band jamming on our proposed ARA algorithm. The channel estimation error introduces degradation on the system performance such that the performance of the ARA can be worse than that of the EPA when the channel estimation error is large. We also showed that partial-band jamming degrades the system performance over full-band jamming, especially in the high SINR regions.

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