A Simulation Comparison of Distributed Power Control Algorithms for Wireless Communications

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***Abstract*—A major challenge in the operation of wireless communication systems is the effective use of radio resources to promote the quality and efficiency of the system. One such component is the power control in the mobile terminals, which is a measure of energy efficiency. Controlling the power at each wireless user not only increases the operating life of the battery, but also increases the overall system capacity by reducing the interference at each user. Game theory, a powerful tool in modelling interaction between self interested users and predicting their choice of strategies was recently used for power control in wireless data systems.**

Many power control algorithms have been proposed in the past decade. In this paper, we study these algorithms, present a suite of distributed power control algorithms, implement them and compare to a game theoretic algorithm. Here the concept of constraining the SIR of each user is introduced to increase the rate of convergence of these algorithms. It is also seen that the utilities increase as a result of constraining the SIR in some algorithms. We present simulation results which illustrate the utilities obtained by these algorithms, and their convergence to specified Quality of Service (QoS). Further, we compare the results obtained by these algorithms with the power control based on game theory.

I. INTRODUCTION

In wireless communication systems, the aim of power control is to assign each user a transmitter power level such that all users satisfy their quality of service (QoS) requirements. An optimum power control algorithm for wireless systems maximizes the number of sessions that can simultaneously achieve a certain quality of service (QoS) objective. QoS objective could be defined in terms of minimum acceptable signal-to-interference ratio and/or the target is the maximum acceptable probability of error. Many power control algorithms suitable for wireless voice transmission have been proposed and analyzed over the past decade. Distributed power control (DPC) algorithm in which mobiles adjust their transmitter powers synchronously in discrete time steps was proposed in [3], and was extended in [4] (CDPC). Another form of distributed power control based on exponential update of powers was proposed in [5] (EDPC). Second order power control algorithms were proposed in [7] (CSOPC), [8], [9] (ISOPC). A power control algorithm based on state space theory was studied in [8], [6] (SSCD). In the distributed power control algorithms, all the users in cell aim to maintain their SIR level towards a specified target level.

The power control algorithms cited above are not appropriate for wireless data transfer [1]. Recently, power control algorithms for wireless data were proposed in [1]. In these models, the QoS of each user was represented by a utility function. The utility function quantifies the level of satisfaction a user gets by using the system resources. Using *game theory* to study power control, a set of powers were obtained which represent the *Nash Equilibrium* point of a non-cooperative game (NPG). Non cooperative power control game with pricing (NPGP), was also shown to decrease the powers and increase the utilities [1]. In [2], network assisted power control which is based on the power update using DPC is shown to maximize the utilities of users while maintaining equal signal to interference ratios for all users.

In this work, the distributed power control algorithms described in [3], [4], [7], [8], [9], [6] are investigated in conjunction with a system used for wireless data transfer. We introduce the concept of constraining the SIR and see its effect on the utilities and the rate of convergence. A comparison is made between the game theoretic based power control algorithm and the distributed power control algorithms when used for data transmission.

II. SYSTEM MODEL FOR POWER CONTROL

A cellular system used in the context of data transfer in the same cell is considered in this work. A power-controlled cellular system is considered where the transmitted powers are continuously adjustable. In the system, every mobile is connected to a base station to communicate. To maintain a connection between the mobile and its station, the SIR at the receiver must not be less than some threshold, which corresponds to a QoS requirement, such as the bit-error rate or utility. Here only the uplink transmission (mobile to base) is considered. The downlink can be treated similarly.

Consider a single-cell of a CDMA wireless communication system with N users (terminals or mobiles) in the cell transmitting data to the same base station. Here each user transmits L information bits in frames (packets) of length M $(M \geq L)$ bits at a fixed rate of R bits/sec. The transmission power of the j^{th} user is denoted as p_j, $j = 1, 2, \ldots N$. The path gain of user j to the base station is h_j, $j = 1, 2, \ldots N$. The signal to

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interference ratio at the user j is given in [1] as

$$\gamma_j = \frac{W}{R} \frac{h_j p_j}{\sum_{k=1, j \neq k}^{N} h_k p_k + \sigma^2} \tag{1}$$

where W is the available spread-spectrum bandwidth [Hz], σ^2 is the AWGN (Additive White Gaussian Noise) power at the receiver. The quality of the connection between the user and the base station will be characterized by the SIR. γ^T is the minimum SIR required for the connection between a user and a base station to be supported. The utility function for user j is defined in [1] as

$$u_j = \frac{LRf(\gamma_j)}{Mp_j} \text{ bits/Joule} \tag{2}$$

where $f(\gamma_j)$ is the efficiency function, defined as the probability of user j to transmit the packet correctly. In the power control game, each user maximizes its own utility in a distributed fashion. In the non cooperative power control game, each user maximizes its own utility in a distributed fashion. Formally, the NPG is expressed as

$$\max_{p_j \in P_j} \quad u_j(p_j, p_{-j}), \text{ for all } j \in N \tag{3}$$

The NPG with linear pricing (NPGP) is expressed as [1]

$$\max_{p_j \in P_j} u_j^c(p_j, p_{-j}) = u_j(p) - c\alpha_j p_j, \forall j \in N \tag{4}$$

III. Simulations

A. Simulation Model

The setup for the simulation experiments to investigate the algorithms discussed above is as follows. We assume that the users are stationary, transmit frames of equal size and there is no forward error correction. We assumed the system parameters for the single cell CDMA system as follows: The total number of bits for frame = 80; The number of information bits per frame = 64; Spread spectrum bandwidth = 10^6Hz; Bit rate = 10^4 bits/second; σ^2, AWGN power at the receiver = 5.10^{-15}Watts; Modulation technique = Non-coherent FSK; $\overline{p}$, Maximum power constraint = 2 Watts. The efficiency function (used in the utility function) is

$$f(\gamma_j) = [(1 - exp(-0.5\gamma_j))]^M$$

We assumed 9 users located at distance d = [310, 460, 570, 660, 740, 810, 880, 940, 1000] meters from the base station. For NPG, the condition which maximizes the utility of a system satisfies $f'(\gamma_j)\gamma_j = f(\gamma_j)$. By solving this equation, we get the value of $\tilde{\gamma} = 12.42 = 10.94$ dB. We used the propagation model $h_j = K/d_j^4$, where d_j (km) is the distance between user j and the base station, K = 0.097.

B. Implementation

We implemented (in Matlab) all the distributed power control algorithms and tested them with the model above. We used a stopping criterion $\|p^t - p^{t-1}\| < \epsilon = 10^4$, where p is the vector of user powers. For Game Theoretic power control, we applied iteratively the best response function until the stopping criterion was satisfied. We imposed the target SIR $\gamma^T = \tilde{\gamma} = 12.42$ to all the other power control algorithms. We also evaluated the utility function with the final power computed by all the power control algorithms.

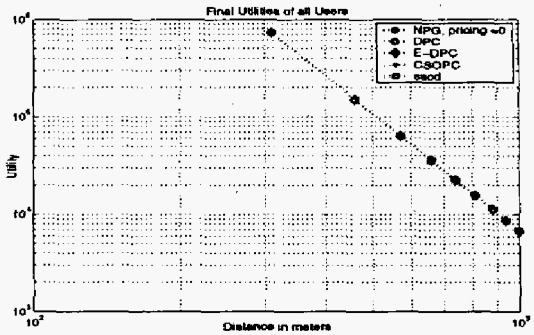

Fig. 1. The final utilities of all the users

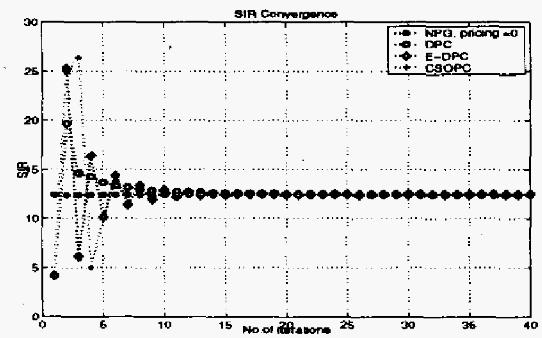

Fig. 2. The convergence of the SIR for DPC, EDPC, CSOPC, NPG

We used the following comparison measures: (1).The final utilities of all users obtained by the algorithms after they reach the target SIR and the stopping criterion is satisfied. (2). The rate of convergence (as the number of steps or iterations) of the algorithms to the target SIR. (3). The rate of convergence (as the number of steps or iterations) of the utilities of user-1. (4) The rate of convergence (as the number of steps or iterations) of the power of user-1. For brevity we show the results for only user-1 i.e the user closest to the base station, but all the other users results are also similar.

C. Results

The final utilities of all the users for all the algorithms discussed above are shown in Figure 1. The convergence to the target SIR is shown in Figures 2 and 3. Figure 2 does not include SSCD because of its wide variation of SIR in the first few iterations. In Figures 4 and 5, the utilities and powers are shown for CDPC [4], E-DPC [5], NPG [1], CSOPC [7] and SSCD [6] algorithms.

The final utilities of all the users are the same for CDPC, EDPC, SSCD, CSOPC algorithms for the same target SIR,

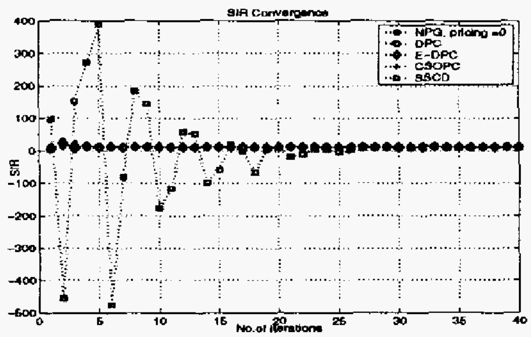

Fig. 3. The convergence of the SIR for DPC; E-DPC, CSOPC, SSCD, NPG

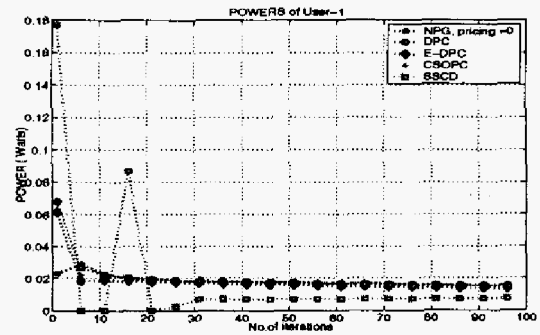

Fig. 5. The powers of different time instants using the original algorithms

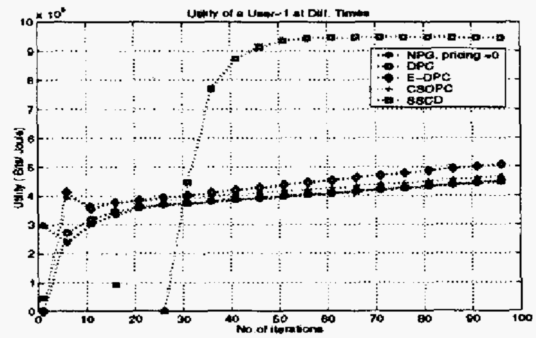

Fig. 4. The utilities at different time instants using the original algorithms

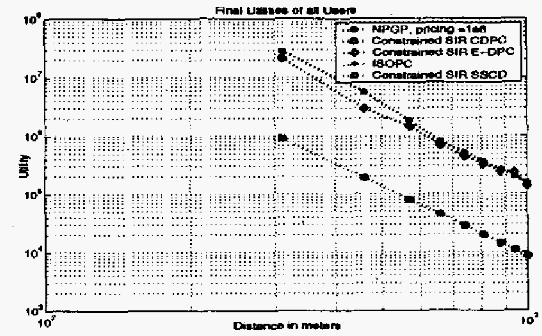

Fig. 6. The final utilities of all the users using SIR Constrained (EDPC, CDPC, SSCD), ISOPC and NPGP algorithms

and they are equal to the utilities obtained by the NPG. Notice NPG and CSOPC converge faster to the target SIR than the DPC and EDPC as seen in Figure 2. Also the convergence of SSCD to the target γ^T is very slow (Figure 3). We can observe that even though the convergence of SIR to the target is faster, the rate of convergence of utilities and powers is slower (Figures 4, 5).

D. Constrained SIR Power Control Algorithms

An efficient power control algorithm converges to the target SIR fast. It can be seen that the distributed power control algorithms discussed above calculate the powers with SIRs below the target level in the initial stages. This is undesirable in the data transmission because when the SIR is below the target level, it may result in loss of packets. One solution to this problem is maintaining the SIR of the user always greater than or equal to the target level. So, here we propose the idea of constraining the SIR. The basic idea of constraining the SIR is: if the SIR at a past instant is less than the target level then adjust the power such the present SIR is equal to the target. The condition used in constraining the SIR is

$$\text{If } \gamma_j < \gamma^T;\text{ then } \gamma_j = \gamma^T$$
$$\text{If } \gamma_j \geq \gamma^T;\text{ then } \gamma_j = \gamma_j$$

It is also to be noted that we cannot obtain a Constrained SIR algorithm for CSOPC and ISOPC because when the powers are adjusted to transmit with the target SIR, the algorithm stops and always gives a power of 1.

The final utilities of all the users is shown for Constrained SIR (CDPC, EDPC, SSCD), ISOPC [9] and NPGP are shown in Figure 6. The convergence to the target SIR is shown in Figure 7. In Figure 8 and 9, the utilities and powers at different times are shown using Constrained SIR (CDPC, EDPC, SSCD), NPGP, ISOPC algorithms. In Figure 10, the final SIRs of all the users is shown for Constrained SIR (CDPC, EDPC, SSCD), NPGP, ISOPC.

The final utilities of all users using ISOPC, Constrained SIR (CDPC, SSCD) are much lower when compared to constrained SIR EDPC and NPGP (Figure 6). There is a significant increase in final utilities of all the users using constrained SIR EDPC. If the SIR is constrained the convergence of constrained SIR SSCD is lot faster and the convergence of all the other algorithms has also increased as seen in Figure 7. Observe that the utilities of all SIR constrained algorithms converge fast. Also, the utilities and powers obtained by Constrained SIR EDPC are comparable to that of NPGP. It should also be noted (Figure 10) that the SIRs at equilibrium in NPGP are higher for users closer to the base station ($\gamma_j >$

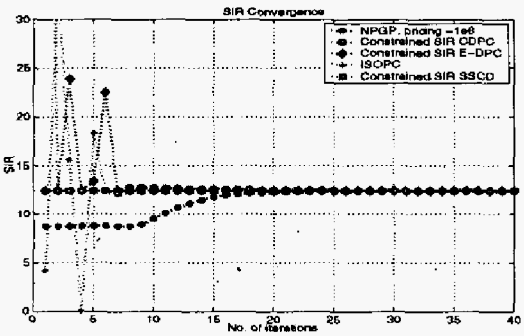

Fig. 7. The convergence of the SIR to the target using SIR Constrained (CDPC, EDPC, SSCD), ISOPC and NPGP

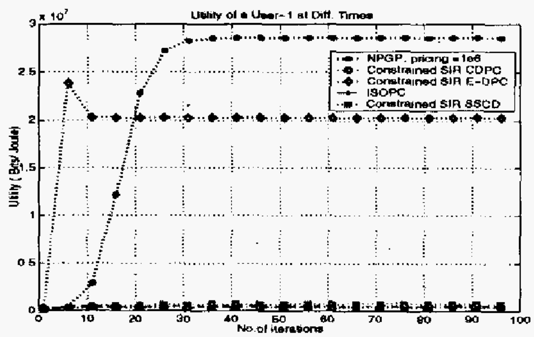

Fig. 8. The utilities at different time instants using SIR Constrained (CDPC, EDPC, SSCD), ISOPC and NPGP

γ_i if $d_j < d_i$), but in the case of Constrained SIR EDPC, the SIRs of all the users are equal to the target ($\gamma_j = \gamma^T = 12.42$ for all $j \in N$).

IV. Conclusion

The distributed power control algorithms used in wireless systems were implemented and simulated for the wireless data service systems. Simulation results were used to show 1) the convergence rates of these algorithms to a specified target SIR, 2) the power levels and the utilities obtained. The concept of constraining the SIR so that for each user it is greater than or equal to the target SIR was introduced into these algorithms. It was also shown that the constrained SIR distributed power control algorithms have a faster rate of convergence. It was also observed by the simulations that the constrained SIR Exponential Distributed Power Control (EDPC) gave utilities which are greater than that power control using NPGP. A study on the comparison of the performance of all the algorithms was presented.

Future work would include the analytical study for the increase in the rate of convergence in the Constrained SIR algorithms, and the study of the Constrained SIR EDPC which converges to lower powers.

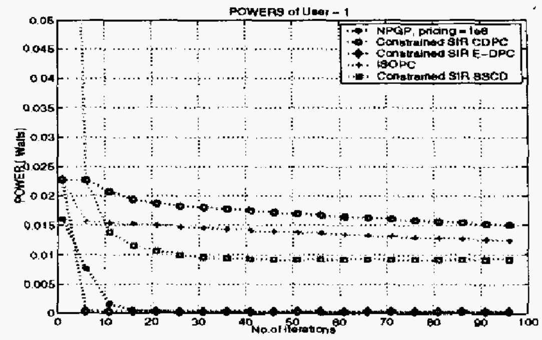

Fig. 9. The powers at different time instants using SIR Constrained (CDPC, EDPC, SSCD), ISOPC and NPGP

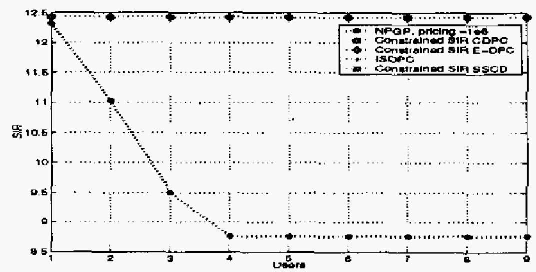

Fig. 10. The final SIRs of all the users using SIR Constrained (CDPC, EDPC, SSCD), ISOPC and NPGP

Acknowledgment

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