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Performance Analysis of Nash and Power Balancing Algorithms for SIR-Based Power Control in CDMA Networks

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Abstract— This paper incorporates a comprehensive study about the distributed power control algorithm in cellular communication systems. The algorithm requires only interference power estimations and/or signal-to-interference ratio (SIR) estimations form the base station, and converge even in cases where limits on available power render the target SIR unattainable. Power control plays an important role to high demand for wireless communication services shows the need for technology to further increase the capacity of cellular communication systems. The capacity of the system is maximized if the transmitter's power control is controlled so that its signal arrives at base station with minimum required signal-to-interference ratio. Nash equilibrium power provides substantial power savings as compared to the power balancing algorithm, while reducing achieved SIR only slightly. Simulations show that the benefit of the Nash equilibrium power control over the power balancing solution increases as receiver noise power or number of users in the cell increases.

Index Terms— Power Control, CDMA, Nash Algorithm, Power Balancing Algorithm, SIR, Cellular Communication, Wireless Communication

1 Introduction

The demand of communicating each other, whatever places the receiver may be, wireless technology started to emerge. By the recent years, the wireless communication become so popular that it is now facing a great challenge to meet the demand to have different types of service in a cost effective way. To support the demand a way variety of research is going on worldwide to find out a solution of the ever increasing wish of mankind using the limited resource. Generally, the high speed quality, high capacity and lower power consumption are major goals in cellular radio communication systems. Power control is one of the several techniques used to achieve these goals. Power control regulates the signal strength to reduce the overall interference [1]. In CDMA the system capacity is maximized if each mobile transmitter power level is controlled so that its signal arrives at the cell site with the minimum required signal-to-interference ratio [2]. If the signal powers of all mobile transmitters within an area covered by a cell site are controlled then the total signal power received at the cell site from all mobiles will be equal to the average received power times the number of mobiles operating in the region of coverage. A tradeoff must be made if a mobile signal arrives at the cell site with a signal that is too weak and often the weak user will be dropped. If the received power from a mobile user is too great, the performance of this mobile unit will be acceptable but it will add undesired interference to all other users in the cell. A block diagram illustrating the power control structure [3] is shown in Fig. 1.

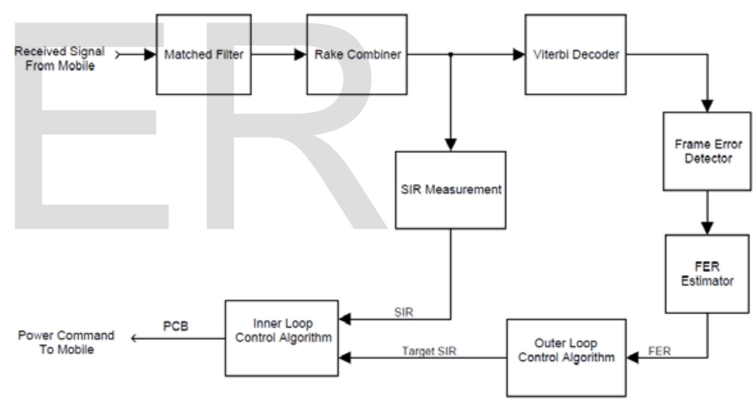

Fig. 1: Block diagram for implementation of power control in CDMA systems.

2 Review of Literature

One of the most common approaches to closed-loop power control in wireless communication networks is SIR balancing, also called power balancing. The SIR balancing solution was originally derived for satellite communications by Aein [4] and Meyerhoff [5], and adapted for wireless communications by Nettleton [5] and Zander [6] and [7]. Variations on the SIR balancing algorithm have replaced the target SIR by functions incorporating minimum allowable SIR [8], SIR's of other mobiles [9], and maximum allowable power [10] among others. Variations have been developed to incorporate call admission and handoff [11], base station assignment [12], and economic

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tradeoffs .SIR balancing algorithms (SBA's) are simple and most can be implemented distributively, but have the disadvantage that convergence can be slow and is guaranteed only if every mobile's target SIR is feasible. To address the convergence issue, a number of algorithms have been developed that shape the dynamics of the controlled power or the convergence of the algorithm [13]. Another class of algorithms seeks to solve a static optimization problem. The well known distributed constrained power control (DCPC) algorithm maximizes the minimum attained user SIR subject to maximum power constraints. Other algorithms minimize power consumption in the presence of large-scale fading or over a set of discrete available power levels. Dynamic optimization has been used to minimize power consumption by formulating power control for log-normal fading channels in a stochastic framework as well as to adaptively optimize quantization of fedback SIR. An alternative framework for developing power control algorithms is based on game theory or economic formulations requiring the specification of a utility or cost function. The use of pricing to promote efficiency and fairness has been discussed extensively. Alpcan et al. [14] recently proposed a Nash game formulation of the SIR-based power control problem in which each mobile uses a cost function that is linear in power and logarithmically dependent on SIR. They establish the existence and uniqueness of the Nash equilibrium solution and consider the effect of various pricing schemes on system performance.

Power control,

$$g_{ij} := \begin{cases} h_i & j = i \\ h_j (s_j{}^T s_i)^2 & otherwise \end{cases} \quad (5)$$

so g_{ij} denotes an effective link gain from the jth user to the base station that specifies the jth user's contribution to the interference affecting the signal of the ith user. We will also define an effective gain matrix G having *(i.j)*th element g_{ij}. Note that in contrast to the case in which background noise power is neglected and the diagonal elements of the gain matrix are set to zero, we cannot write the interference as the product of the gain matrix and power vector, *i.e.* $I \neq Gp$. The Nash algorithm will run in real time with measurements potentially updated every step of the algorithm. This algorithm iteratively updates power according to

$$p_i{}^{(k+1)} = \begin{cases} \dfrac{\gamma_i^{tar}}{g_{ii}} I_i^{(k)} - \dfrac{b_i}{2c_i} (\dfrac{p_i^{(k)}}{\gamma_i^{(k)}} & \text{If positive} \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where $p_i^{(k)}$ is the power of the i the mobile and $I^{(k)}_i$ the measured interference experienced by the ith mobile at the kth step of the algorithm. Recall that $I_i{}^{(k)} = \sum_{j \neq i} g_{ij} p_j{}^{(k)} + \eta_i$. In implementation, of course, power cannot become negative so there is an implicit assumption that whenever this expression is negative, the assigned power will be zero. The power balancing (also called SIR-balancing) algorithm iteratively updates power according to

$$p_i^{(k+1)} = \left(\frac{\gamma_i^{tar}}{\gamma_i^{(k)}} \right) p_i^{(k)} \quad (7)$$

3 NASH AND POWER BALANCING ALGORITHMS

Power control for either the uplink (reverse link) or the downlink (forward link) can be considered. In the former case, a desirable property for a power control algorithm is the sufficiency of measurements available at the mobile for computing the power updates. Such algorithms can be implemented without reliance on communication with either the base station or other mobiles and hence are called distributed. Note that, it has been shown that the same problem formulation can be applied to various types of both uplink and downlink scenarios so our discussion here is not exclusively applicable to uplink power control. The goal in the power control of wireless systems is to ensure that no mobile's SIR γ_i falls below its threshold γ_i^{tar} chosen to ensure adequate QoS, i.e. to maintain

$$\gamma_i \geq \gamma_i^{tar}, \forall_i, \quad (1)$$

where the subscript i indexes the set of mobiles. In IS-95, this threshold is calculated for the individual mobile to maintain a satisfactory frame-error rate (FER). From the mobile's perspective, however, whether the other users meet their QoS requirements is irrelevant. For this reason, the framework of non-cooperative game theory [37] is well suited for analyzing and solving the power control problem. Considering the uplink for a single cell CDMA system with N users, we designate

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the transmitted power and SIR for the *i*th user by p_i and γ_i, respectively. We denote the background (receiver) noise power within the user's bandwidth by η_i is treated as constant. We use a "snapshot" model, assuming that link gains evolve slowly with respect to the SIR evolution. In the problem formulation, the SIR of the ith mobile is

$$\gamma_i = \frac{h_i p_i}{\sum_{j \neq i} h_j p_j c_{ij} + \eta_i} \qquad (2)$$

where h_j is the attenuation from the *i*th mobile to the base station and c_{ij} is the code correlation coefficient. The attenuation is calculated from the distance r_i between the mobile and base station to be $h_i = A/r_i^{\alpha}$ in the absence of shadow and fast fading. A is a constant gain and α is usually between 3 and 6. We will provide realistic values for these constants in the simulation section, Section III. The code correlation coefficient c_{ij} is computed from the signatures s_i and s_j to be $c_{ij}=(s_j^T s_i)^2$. We note that this model is consistent with the general power control problem for wireless communication systems in which the SIR of mobile i is given by

$$\gamma_i = \frac{g_{ii} p_i}{I_i(p-i)} = \frac{g_{ii} p_i}{\sum_{j \neq i} g_{ij} p_j + \eta_i} \qquad (3)$$

with the interference given by

$$I_i(p-i) := \sum_{j \neq i} g_{ij} p_j + \eta_i. \qquad (4)$$

we have used the subscript "*-i*" to indicate that the interference depends on the powers of all users except the *i*th. If we define a power vector *p* having its element p_i, and an interference vector I having ith element $I_i(p\text{-}i)$, the subscript indicates that the *i*th element of the interference vector depends on all but the *i*th element of the power vector. Comparing (3.10) and (3.11) we see that for CDMA uplink power control,

$$g_{ij} := \begin{cases} h_i & j = i \\ h_j (s_j^{\,T} s_i)^2 & otherwise \end{cases} \qquad (5)$$

so g_{ij} denotes an effective link gain from the *j*th user to the base station that specifies the *j*th user's contribution to the interference affecting the signal of the *i*th user. We will also define an effective gain matrix G having *(i.j)*th element g_{ij}. Note that in contrast to the case in which background noise power is neglected and the diagonal elements of the gain matrix are set to zero, we cannot write the interference as the product of the gain matrix and power vector, *i.e.* I≠Gp. The Nash algorithm will run in real time with measurements potentially updated every step of the algorithm. This algorithm iteratively updates power according to

$$p_i^{(k+1)} = \begin{cases} \dfrac{\gamma_i^{tar}}{g_{ii}} I_i^{(k)} - \dfrac{b_i}{2c_i}\left(\dfrac{p_i^{(k)}}{\gamma_i^{(k)}}\right) & \text{If positive} \\ 0 & \text{otherwise} \end{cases} \qquad (6)$$

where $p_i^{(k)}$ is the power of the i the mobile and $I^{(k)}_i$ the measured interference experienced by the *i*th mobile at the *k*th step of the algorithm. Recall that $I_i^{(k)} = \sum_{j \neq i} g_{ij} p_j^{(k)} + \eta_i$. In implementation, of course, power cannot become negative so there is an implicit assumption that whenever this expression is negative, the assigned power will be zero. The power balancing (also called SIR-balancing) algorithm iteratively updates power according to

$$p_i^{(k+1)} = \left(\frac{\gamma_i^{tar}}{\gamma_i^{(k)}}\right) p_i^{(k)} \qquad (7)$$

4 Result and Discussion

We used Matlab simulation with γ^{tar} = 5.0 and b = 5 $(mw)^{-1}$ and c = 1 for random configuration for Nash algorithm and γ^{tar} = 5.0 for random configuration for power balancing algorithm of 3 users and noise power was η = 0.01. Our initial power for all mobiles was $p_i^{(0)} = 0$ for Nash algorithm and $p_i^{(0)}$ = 2.22e-16 for power balancing algorithm . The average power $\overline{p}_i^{Nash}$ = 0.6482 mW and SIR, $\overline{\gamma}_i^{Nash}$ = 4.6451 as opposed to 5.0 for Nash algorithm and power $\overline{p}_i^{PB}$ = 7.382 mW and SIR, $\overline{\gamma}_i^{PB}$ = 4.9981 as opposed to 5.0 for power balancing algorithm. The power balancing algorithm converged very slowly compare with Nash algorithm but the total power consumption is not very high as shown in Fig. 2.When we increased the target SIR, γ^{tar} = 7.0 and b = 5 $(mw)^{-1}$ and c = 1 for Nash algorithm, the Nash algorithm converged very fast (mainly after 24 iterations), as shown in Fig 2. The average power for Nash algorithm $\overline{p}_i^{Nash}$ = 3.304 mW and SIR, $\overline{\gamma}_i^{Nash}$ = 5.2 as opposed to 7.0. And the target SIR, γ^{tar} = 7.0 for power balancing algorithm, the total power consumption is very high but the algorithm converged very fast. The average power for power balancing algorithm $\overline{p}_i^{PB}$ = 78.441 mW and SIR, $\overline{\gamma}_i^{PB}$ = 5.6482 as opposed to 7.0.

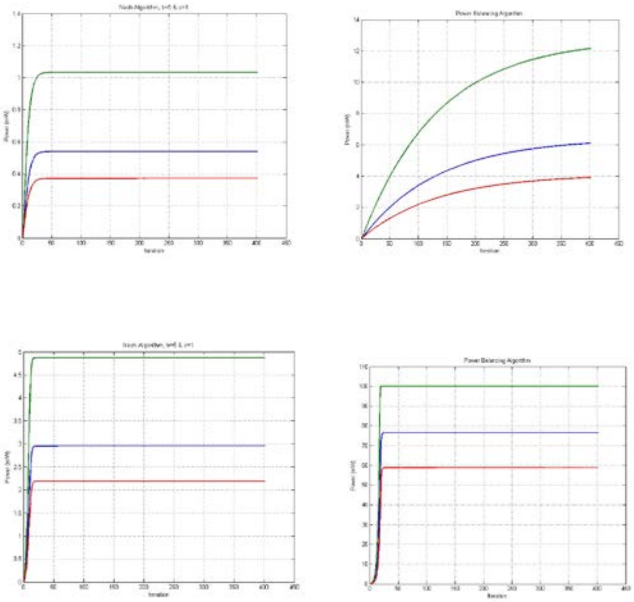

Fig 2. Power consume of Nash algorithm and power balancing algorithms for 3 users with γ^{tar} = 5.0 and γ^{tar} = 7.0 for all mobiles.

We used the Nash algorithm for gamma with γ^{tar} = 5.0 and b = 0.5 $(mw)^{-1}$ and c = 1 for random configuration of 3 users and noise power was η = 0.01. Our initial power for all mobiles was $p_i^{(0)} = 0$ for this algorithm. The Nash algorithm converged not very fast (after 176 iterations), as shown in Fig. 3. By running the Nash algorithm for 400 iterations we have obtained the following results P = [1.6334 3.2205 1.0684] and γ = [4.9170 4.8334 4.9460]. The average power $\overline{p}_i^{Nash}$ = 1.9741 mW and the average SIR, $\overline{\gamma}_i^{Nash}$ = 4.8988 as opposed to 5.0.

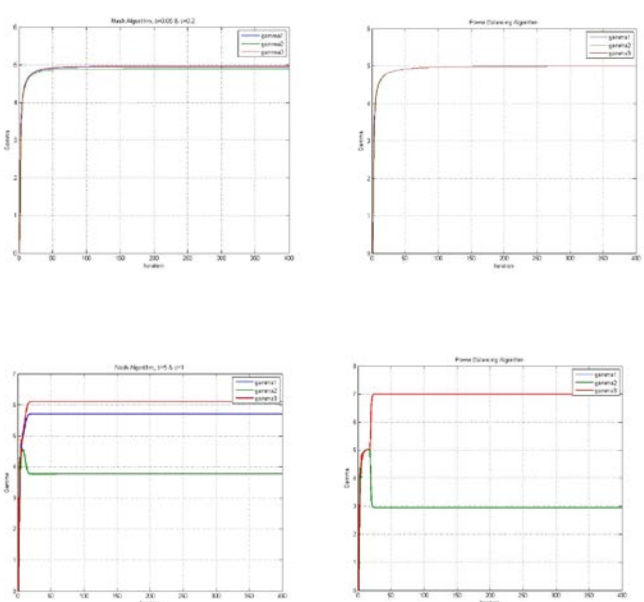

Fig 3. Target signal to interference ratio (SIR) of Nash algorithm and power balancing algorithm for 3 users with γ^{tar} = 5.0 and γ^{tar} = 7.0 for all mobiles.

5 Conclusion and Future Work

With our algorithm, we obtained lower individual powers with comparable or faster convergence by compromising slightly on SIR values. Exploiting this tradeoff, the proposed algorithm was able to handle many more users than the power balancing algorithm and to produce the Nash equilibrium in cases where the power balancing problem has no solution. The algorithm can easily be implemented in a distributed manner, and has the advantage that mobiles choose whether or not to transmit based on their own valuations of the trade-offs between power usage and QoS as represented in their cost functions. We have also demonstrated that the suboptimal controller strategy outlined above has the potential to power and improve quality of service. An interesting topic for future research is the development of efficient algorithms for use by the base station in identifying when to drop calls and which mobile's calls to drop.

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