Performance evaluation of power control algorithms in wireless cellular networks

C Temaneh-Nyah, V Iita
Department of Electronics and Computer Engineering, University of Namibia

Email: clementtemaneh@yahoo.com

Abstract. Power control in a mobile communication network intents to control the transmission power levels in such a way that the required quality of service (QoS) for the users is guaranteed with lowest possible transmission powers. Most of the studies of power control algorithms in the literature are based on some kind of simplified assumptions which leads to compromise in the validity of the results when applied in a real environment. In this paper, a CDMA network was simulated. The real environment was accounted for by defining the analysis area and the network base stations and mobile stations are defined by their geographical coordinates, the mobility of the mobile stations is accounted for. The simulation also allowed for a number of network parameters including the network traffic, and the wireless channel models to be modified. Finally, we present the simulation results of a convergence speed based comparative analysis of three uplink power control algorithms.

1. Introduction

Technological advances in the area of wireless communication have given rise to significant increase in the number of mobile wireless devices. The challenge of future wireless systems is to accommodate the increasing demands for wireless services as well as new high-data-rate applications that require performance to meet system Quality of Service (QoS) [1]. An essential radio resource management method in the development of optimal radio transmission like CDMA cellular communication systems is the transmitter power control. Power control intents to control the transmission power levels in such a way that the required QoS for the users is guaranteed with lowest possible transmission powers [2]. Studies also indicate that all forms of electromagnetic radiations adversely affect human and animal health. The biological effects of non-ionizing radiations are extensively examined in a report published by the International Commission on Non-Ionizing Radiation Protection [3]. Transmitting with lowest possible transmission powers in a complex electromagnetic environment can greatly reduce the radiations level and its effect on the operation of radio communication equipments and on biological objects. Mobile radio network based on CDMA technology uses a common frequency band for the organization of traffic channels. Frequency division is used only for duplex. Therefore interference to signals of base stations (BS) are signals of other BS, and interference to signals from the mobile station (MS) are other MS that are in same cell as well as in neighbouring cells. The main problem in the construction of a mathematical model of a CDMA network is to determine the transmission power level in the forward and reverse traffic channels. In a deployed CDMA network, transmission power level of a MS $P_{MS}$ is a function of the
signal-to-noise plus interference ratio at the BS receiver input $\gamma_{BS} : P_{MS} = f(\gamma_{BS})$, and the level of radiated BS partial power $P_{BS}$ is a function of the signal-to-noise plus interference ratio MS receiver input $\gamma_{MS} : P_{BS} = f(\gamma_{MS})$. The value of the signal-to-noise plus interference ratio $\gamma$ at a given point in space is dependent on several parameters including the transmitters’ power and the propagation loss amongst many others as shown in expression (4) and can be expressed as $\gamma = \varphi(P_{........})$. Thus, obtaining the following expression:

$$P = f(\gamma) = f(\varphi(P_{........}))$$  \hspace{1cm} (1)

The solution of (1) is made difficult by its nonlinear nature, as well as for the fact that at any point in space, the calculation of the value of $\gamma$ requires knowledge of the power emitted by all the network transmitters, but this power cannot be calculated if the value of $\gamma$ is unknown, which again depends on $P$. This results in a vicious circle and therefore excludes a simple solution.

Power control is a well-known strategy to minimizing key performance parameters including [4-6]:

- Energy usage: providing the minimum power required for each connection, this implies - reduce battery consumption hence longer battery life especially for the MS which mitigates frequent battery charging.
- Interference Mitigation: reduces the effects of co-channel and adjacent channel interference.
- Improve network capacity: allows more users to be connected to the network and thus increasing capacity of the network.

Environmental significance: By minimizing the energy usage in a wireless cellular communication network through the implementation of efficient PC algorithms, the following environmental benefits can be derived: Reduce environmental pollution: lower rate of battery ware out and thrown into the environment. Human health: Some studies show that exposure to electromagnetic field has an adverse effect on the human health. The effect depends on the intensity of the electromagnetic field. Therefore achieving a minimum transmit power for each transmitter in the network can significantly reduce the field intensity in the environment and hence less risk to the human being. There has been significant theoretical study and simulation of power control using Signal-to-interference (SIR) based and bit-error-rate (BER) based algorithms. Currently, an algorithm for power control in CDMA network is implemented in Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT) and it uses the relationship between power in the traffic channel and bit energy to noise ratio for power control. This data exist only for a narrow range of bit energy to noise ratio, and therefore limits the use of this approach. However, solutions found by this effort may not be applicable in real deployed systems because of simplified assumptions in the system’s models such as the use of a rigid structure in defining the fixed distances between the base stations, i.e., the real geographical coordinates of base stations are not considered. Therefore in this paper, we consider implementing the power control by making use of real network data. We consider different power control algorithms in section 2.

2. Power control algorithms

Different algorithms for different wireless communication systems have been studied e.g. centralized, distributed algorithms etc. Centralized Power Control involves a central controller with information of all the link gains of the system. Link gains are utilized to find the optimal solution to control the power in all the links simultaneously. However, this algorithm is practically unrealizable due to equipment complexity and bandwidth consideration. In this paper, we consider the distributed constraint power control (DCPC) and the fixed step power control (FSPC) algorithms which are examples of iterative algorithms and are considered in [2] and described respectively by the following expressions:

FSPC: $P_{MS}(n) = \min \{P_{MS,\text{max}}^\prime, P_{MS}(n-1) + \Delta P_{MS} \times \text{sign}(e(n-1))\}$ \hspace{1cm} (2)

DCPC: $P_{MS}(n) = \min \{P_{MS,\text{max}}^\prime, P_{MS}(n-1) + \Delta P_{MS} \times e(n-1)\}$ \hspace{1cm} (3)

$P_{MS}(n)$ is the MS traffic power at the n-th iteration, $P_{MS,\text{max}}^\prime$ is the maximum transmit traffic power for the MS, $\Delta P_{MS}$ is the MS fixed power update step, $e(n-1)$ is the error which is the difference between targeted $\gamma_{BS}^{\text{target}}$ and previous values $\gamma_{BS}(n-1)$ of the signal-to-noise plus interference ratio.
at the BS, [dB]. The bit energy-to-interference-plus-noise ratio $\gamma_{BS,i,j}$ in the reverse traffic channel between MS and BS with indexes i and j can be estimated by the expression [2]:

$$\gamma_{BS,i,j} = \left( \frac{P_{pc,MS}^i G_{MS,i,j}(\theta_{ij})}{P_{N,BS} + P_1 + P_2 + P_{ext}} \right) \times \frac{L_{ij}}{W/R} \times G_{BS,i,j}(\theta_{ij}) \times L_{ij}$$

where

$$P_1 = (1 - \beta) \sum_{k \neq i} v_k \frac{P_{pc,MS,k,j}^i G_{MS,k,j}(\theta_{kj})}{L_{kj}}$$

$$P_2 = \sum_{m=1}^{N_{BS}} \sum_{m \neq j} v_1 \frac{P_{pc,MS,1,j} G_{MS,1,j}(\theta_{ij})}{L_{ij}}$$

$P_{pc,MS,i,j}$ is the emissions power of MS in the reverse traffic channel between MS and BS with indexes i and j respectively; $G_{BS,i,j}(\theta_{ij})$ is the antenna gain of BS with index j in the direction towards the MS with index i; $L_{kj}$ is the propagation loss between MS and BS with indexes k and j respectively; $P_{N,BS}$ is the intrinsic noise power of BS; $\beta < 1$ is the orthogonality factor, which allows us to account for the violation of orthogonality of the spreading pseudo-random sequences; $N_{BS}$ is the number of BS; $N_m$ is the set of MS indexes served by BS with index m; $v_k$ is the mobile user activity which is a random variable with binomial distribution; $N_{BS}$ is the number of BS; $W$ is the chip rate; $R$ is the transmitted information rate.

We can observe that in the case of stationary channels, if $\Delta P_{MS} = 1$, in the algorithm for DCPC then $e(n - 1)$ represents the power update for which $e(n) = 0$.

A different algorithm called the Adaptive Step Power Control (ASPC) algorithm can be defined as

$$P(n + 1) = \min \left\{ P_{max}, P(n) + \Delta P \tilde{e}(n) \right\},$$

such that $\tilde{e}(n)$ is an adaptive coefficient for power update express as:

$$\tilde{e}(n) = a(n) \tilde{e}(n - 1) + \delta u(n) \quad (7)$$

where $\delta$ is a parameter which determine the rate of power update, $u(n) = \text{sign}(e(n))$ is the controlling function. Initial values can be taken as $\tilde{e}(0) = 0; u(0) = 1$. Parameter $a(n)$ is defined as follows:

$$a(n) = \frac{1}{2} \left[ 1 + u(n) u(n - 1) \right] \quad (8)$$

i.e.

$$a(n) = \begin{cases} 1, & u(n) = u(n - 1) \\ 0, & u(n) \neq u(n - 1) \end{cases}$$

Therefore, an Adaptive Step Power Control (ASPC) algorithm can be written as

$$P(n + 1) = \min \left\{ P_{max}, P(n) + \Delta P \tilde{e}(n) \right\} \quad (9)$$

The algorithms FSPC and ASPC has different rate of power update. An example of the power update for these algorithms in the case of $u(n) = 1 \ n = 0,1,2,\ldots$ is shown in table 1 and the plot as shown in figure 1.
Table 1: Rate of power update

| Algorithm | Power $P(n)$ | Rate of change |
|-----------|--------------|----------------|
| FSPC      | $P(0) + n\Delta P$ | linear         |
| ASPC      | $P(0) + \Delta P \cdot \delta_c \cdot \frac{n(n+1)}{2}$ | quadratic      |

3. Simulation Results

A simulation platform was developed to simulate and study the power control algorithms (FSPC (2), DSPC (3) and ASPC (9)) for a deployed network while accounting for all the parameters in (4). The relationship between a reverse traffic channel power, the total reverse traffic channel power versus the iteration number for the ASPC, FSPC, and DCPC algorithms for $\Delta P = 2$, $\delta_c = 1$ are presented in figure 2 and figure 3 respectively.

Figure 1. Rate of power update

Figure 2. Reverse traffic channel power vs. Iteration number

Figure 3. Total reverse traffic channel power vs. Iteration number

4. Conclusion

A platform enabling the simulation of power control in an operational network has been studied. Three power control algorithms have been compared based on the convergence speed. The results shows that the ASPC converges (25 iterations) faster than the DCPC (40 iterations) and FSPC (60 iterations).

5. Reference

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