Distributed Power Control for Cooperative Networks

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***Abstract*—In wireless communication systems, transmitted power is regulated to provide each user an acceptable connection by limiting the interference caused by other users. We consider power control in a cooperative mobile-to-base communication system consisting of multiple sources, multiple relays and a base as a destination. This paper introduces two power control scenarios. One is the case of fixed source power and relay gain control(FSP-RGC), the other is simultaneous control for source power and relay gain(SC-SPRG). For the above two scenarios, distributed power control algorithms are provided, respectively. We prove that the proposed algorithms are standard and consequently they converge to a fixed point, respectively. Numerical simulation shows that FSP-RGC converges faster than SC-SPRG.**

I. Introduction

POWER control is an important component of the design of a wireless system, as the capacity of which depends heavily on how mutual interference among different users is managed. Since Zander's early work on power control [1], there have been many research studies on developing distributed power control algorithms. The objective of power control is mainly to meet given signal-to-interference and noise ratio (SINR) requirements of individual users. For this purpose, many power control algorithms have been developed (e.g.,[2]-[6]). To analyze the convergence of these algorithms, Yates established a unified framework in 1995 [7] -a seminal work in the area of power control. Sung and Leung generalize Yates' result and establish a new framework, which is applicable to system supporting opportunistic communications [8].

Cooperative relaying is designed so that users can assist other users while still being able to send their own data. Cooperative relaying has been shown to be a promising technique for spatially dispersed nodes in wireless networks to relay signals for each other in order to exploit spatial diversity in fading channels [9], [10]. Cooperative relaying schemes have been studied and analyzed in various domain. One of the recent studies concerns power allocation in wireless cooperation communication.

This paper addresses simple convergent algorithms for cooperative networks where multiple sources and relays exist. Proposed iterative algorithms have been designed for distributed implementation in dynamic systems with time varying radio channels. It is noted that the power control framework in [7] can be applied the proposed algorithms.

We introduce two scenarios for cooperative power control, one is that only relays control their gain while the power of the source nodes is constant, the other is that the simultaneous control for both source power and relay gain. We derive new interference functions for cooperative networks and then show how the proposed algorithms converge to a desired transmission quality.

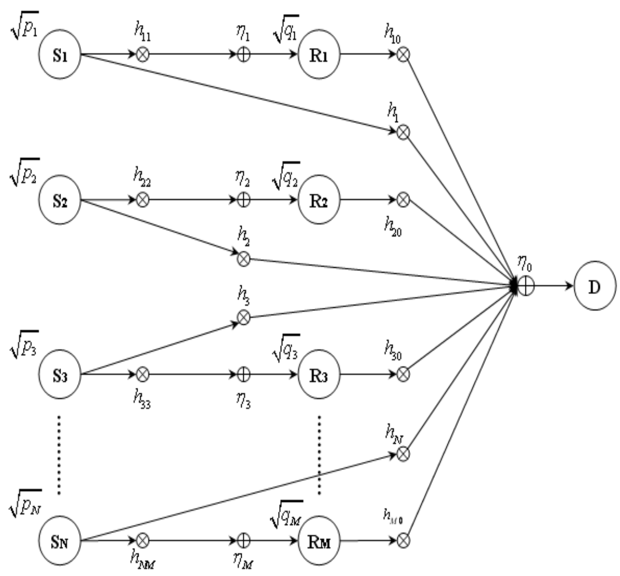

Fig. 1. System Model

The rest of the paper is organized as follows. In Section II, we introduce the system model. In Section III, we present the idea of power control algorithms for cooperative networks and we address a new class of interference functions. In Section IV, we present convergence properties which are designed for cooperative networks. In Section V, we present our simulation results. Finally, we draw a conclusion in Section VI.

II. System Model

We consider cooperative mobile-to-base communication (i.e., Uplink of a cellular network) consisting of N source nodes, M relays and a destination of the base. Fig. 1 denotes the system model. We assume a relay node can convey signals from only one source, so actually the numbers of sources and relays is same. We use s, r, and d to denote the source, relay and destination node, respectively. Let $\mathbf{p} = (p_1, p_2 \cdots, p_N)$ where p_i is the transmit power of source i, and $\mathbf{q} = (q_1, q_2, \cdots, q_M)$ where q_j is the gain of relay j. Denote the link gain between the transmitter of ith node and the receiver of jth node is denoted by h_{ij} and the link gain between the ith source node and the destination by h_i. Let η_j be the noise power at the receiver j of each node. We assume the link gain does not change during power control processes.

$\tilde{S}$ denotes a set of active source nodes, R a set of candidate nodes for relaying and $\tilde{R}$ a set of active relaying nodes. Let $\tilde{R}_s$ be a set of selected nodes for relaying from source s, $\tilde{R} = \bigcup_{s\in\tilde{S}} \tilde{R}_s$.

Let $\gamma_i(p)$ be the SINR of user i ($i \in \tilde{S}$), then traditional SINR at receiver k is expressed as

$$\gamma_k = \frac{p_i h_{ik}}{\sum_{i\neq j} p_j h_{jk} + \eta_k}. \quad (1)$$

In [7], for a broad class of power controlled systems the users' SINR requirements can be described by a vector inequality of interference constraints of the form:

$$\mathbf{p} \geq \mathbf{I}(\mathbf{p}), \quad (2)$$

A power vector $\mathbf{p} \geq 0$ is called a feasible solution if it satisfies the constraints (2). For a system with interference constraints (2), we will examine the iterative power control algorithm,

$$\mathbf{p}(t+1) \geq \mathbf{I}(\mathbf{p}(t)). \quad (3)$$

Conventional power control aims at finding a suitable power vector so that the SINR requirement of all users can be met. We have the following set of iterative power control functions:

$$p_i(t+1) = \frac{\gamma_t}{\gamma_i(\mathbf{p}(t))} p_i(t), \quad \text{for } 1, 2, \ldots, N. \quad (4)$$

This iterative algorithm is particularly a case in [3]. To ensure system stability, it is important to know whether the power vector converges to a fixed point.

We consider amplify and forward relay protocols. In the first time-slot, a source transmits signals to a relay and the destination, respectively. In the second time-slot, relays forward the received signal from the first time-slot to the destination.

The signals from the direct path and the relay path are combined with maximal-ratio combining (MRC) at the destination. Then SINR of the combined signal can be expressed as

$$\tilde{\gamma}_s = \gamma_s + \delta_r, \qquad s \in \tilde{S}, \quad r \in \tilde{R}_s. \quad (5)$$

where γ_s, δ_r are SINRs of the direct and relay path, respectively. The SINRs are written as equation (6) and (7) shown at the top of the next page, and then the SINR of the combined signal can be expressed as (8).

III. Distributed Power Control Algorithms for Cooperative Networks

In this section, we consider two scenarios for cooperative networks. One of the scenarios is only relay nodes control and update their gains while the power of source nodes is constant. The other is the gain of the relay nodes and power of the source nodes are controlled synchronously.

A. Fixed Source Power and Relaying Gain Control

We show the interference function when relays control their gain only. Assume all sources have the same target value Γ. All users adjust their relay gains so as to hit their targets, then we have the following interference function $\mathbf{I}_r(\mathbf{q}(t))$. Note that the bar used as subscript means constant.

$$q(t+1) = \mathbf{I}_r(\mathbf{q}(t)) = q_r(t) \times \frac{\gamma_t - \bar{\gamma}_s}{\delta_r}. \quad (9)$$

$$\mathbf{I}_r(\mathbf{q}(t)) = (\gamma_t - \bar{\gamma}_s) \times \left[\frac{q_r(t) h_{r0} \left\{ \left(\sum_{\substack{i\in\tilde{S} \\ i\neq s}} \bar{p}_i(t) h_{ir} \right) + \eta_r \right\}}{h_{r0} \bar{p}_s(t) h_{sr}} + \frac{\sum_{\substack{j\in\tilde{R} \\ j\neq r}} q_j(t) h_{j0} \left\{ \left(\sum_{i\in\tilde{S}} \bar{p}_i(t) h_{ij} \right) + \eta_j \right\} + \eta_0}{h_{r0} \bar{p}_s(t) h_{sr}} \right]. \quad (10)$$

B. Simultaneous Control Both for Source Power and Relay Gain

We show the interference function when sources control their power and relays control their gain simultaneously. It is similar to above equations, but in this case we achieve interference functions $\mathbf{I}_s(\mathbf{p}(t))$ of sources and $\mathbf{I}_r(\mathbf{q}(t))$ of relays, respectively.

$$\mathbf{I}_s(\mathbf{p}(t)) = \gamma_t \frac{AB}{h_s B + q_r(t) h_{r0} h_{sr} A}, \quad (11)$$

$$\mathbf{I}_r(\mathbf{q}(t)) = \gamma_t \frac{AB}{\frac{p_s(t) h_s}{q_r(t)} B + p_s(t) h_{r0} h_{sr} A}. \quad (12)$$

where

$$A = \sum_{\substack{i\in\tilde{S} \\ i\neq s}} p_i(t) h_i + \eta_0,$$

$$B = q_r(t) h_{r0} \left\{ \left(\sum_{\substack{i\in\tilde{S} \\ i\neq s}} p_i(t) h_{ir} \right) + \eta_r \right\} + \sum_{\substack{j\in\tilde{R} \\ j\neq r}} q_j(t) h_{j0} \left\{ \left(\sum_{i\in\tilde{S}} p_i(t) h_{ij} \right) + \eta_j \right\} + \eta_0. \quad (13)$$

IV. Convergence of Power Control Algorithms

To prove the convergence of the proposed power control algorithms, we introduce the following definition paraphrased from [7].

Definition : Interference function $\mathbf{I}(\mathbf{p})$ is *standard* if for all $\mathbf{p} \geq 0$ the following properties are satisfied

- Positivity : $\mathbf{I}(\mathbf{p}) > 0$.
- Monotonicity : If $\mathbf{p} \geq \mathbf{p}'$, then $\mathbf{I}(\mathbf{p}) \geq \mathbf{I}(\mathbf{p}')$.
- Scalability : For all $\alpha > 0$, $\alpha\mathbf{I}(\mathbf{p}) > \mathbf{I}(\alpha\mathbf{p})$.

If $\mathbf{I}(\mathbf{p})$ is a standard interference function, the corresponding power control algorithm (2) is called standard and shown to converge to a given target [7]. The convergence properties of the proposed power control algorithms can be described by the following result:

$$\gamma_s = \frac{p_s(t)h_s}{\sum_{\substack{i\in\tilde{S}\\ i\neq s}} p_i(t)h_i + \eta_0}, \tag{6}$$

$$\delta_r = \frac{q_r(t)h_{r0}p_s(t)h_{sr}}{q_r(t)h_r\left\{\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}} p_i(t)h_{ir}\right)+\eta_r\right\}+\sum_{\substack{j\in\tilde{R}\\ j\neq r}} q_j(t)h_{j0}\left\{\left(\sum_{i\in\tilde{S}} p_i(t)h_{ij}\right)+\eta_j\right\}+\eta_0}. \tag{7}$$

$$\gamma_s = \frac{p_s(t)h_s}{\sum_{\substack{i\in\tilde{S}\\ i\neq s}} p_i(t)h_i + \eta_0} + \frac{q_r(t)h_{r0}p_s(t)h_{sr}}{q_r(t)h_r\left\{\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}} p_i(t)h_{ir}\right)+\eta_r\right\}+\sum_{\substack{j\in\tilde{R}\\ j\neq r}} q_j(t)h_{j0}\left\{\left(\sum_{i\in\tilde{S}} p_i(t)h_{ij}\right)+\eta_j\right\}+\eta_0}. \tag{8}$$

A. Fixed Source Power and Relaying Gain Control

We consider a case which in sources power is fixed and relays control their gain by themselves

Proposition 2 : The proposed power control algorithm where source power is fixed and relay gain control is standard.

Proof : From (10), we observe that

$$q_r(t)h_{r0}\left\{\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}}\bar{p}_i(t)h_{ir}\right)+\eta_r\right\}+ \sum_{\substack{j\in\tilde{R}\\ j\neq r}} q_j(t)h_{j0}\left\{\left(\sum_{i\in\tilde{S}}\bar{p}_i(t)h_{ij}\right)+\eta_j\right\}+\eta_0>0. \tag{14}$$

$$h_{r0}\bar{p}_s(t)h_{sr}>0. \tag{15}$$

Thus, if $(\Gamma-\bar{\gamma}_s)>0$, the positivity property is satisfied. If not, no needs to select a relay. Next, from (12) we verify the monotonicity property.

$$\left(q_r(t)-q_r'(t)\right)\left\{h_{r0}\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}}\bar{p}_i(t)h_{ir}+\eta_r\right)\right\}+ \sum_{\substack{j\in\tilde{R}\\ j\neq r}}\left(q_j(t)-q_j'(t)\right)\left\{h_{j0}\left(\sum_{i\in\tilde{S}}\bar{p}_i(t)h_{ij}+\eta_j\right)\right\} \geq 0. \tag{16}$$

Since $q\geq q'$, then $q_r(t)-q_r'(t)\geq 0$, $q_j(t)-q_j'(t)\geq 0$. Thus, $\mathbf{I}(\mathbf{q}(t))\geq\mathbf{I}(\mathbf{q}'(t))$, then the monotonicity property is satisfied.

$$\alpha q_r(t)h_{r0}\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}}\bar{p}_i(t)h_{ir}\right)+ \alpha\sum_{\substack{j\in\tilde{R}\\ j\neq r}} q_j(t)h_{j0}\left(\sum_{i\in\tilde{S}}\bar{p}_i(t)h_{ij}+\eta_j\right)+\alpha\eta_0- \alpha q_r(t)h_{r0}\left(\sum_{\substack{i\in\tilde{S}\\ i\neq s}}\bar{p}_i(t)h_{ir}+\eta_r\right)- \sum_{\substack{j\in\tilde{R}\\ j\neq r}}\alpha q_j(t)h_{j0}\left(\sum_{i\in\tilde{S}}\bar{p}_i(t)h_{ij}+\eta_j\right)+\eta_0>0. \tag{17}$$

Inequality $\alpha\eta_0-\eta_0=\eta_0(\alpha-1)>0$ hold since $\alpha>1$, therefore $\alpha\mathbf{I}(\mathbf{q}(t))>\mathbf{I}(\alpha\mathbf{q}(t))$ if all the background noises at mobile receivers are positive.

B. Simultaneous Control for Both Source Power and Relay Gain

Proposition 3 : The proposed power control algorithm in which source control their power and relay control their gain simultaneously is standard.

Proof : We use (10), (11), and (12) equations for proof. To do so, we verify that the convergence properties.

Let $A\geq A'$, $B\geq$B'.

$$h_sBB'(A-A')+ q_r(t)h_{r0}h_{sr}A'A(B-B')\geq 0, \tag{18}$$

and

$$\frac{p_s(t)h_S}{q_r(t)}B'B(A-A')+ AA'p_s(t)h_{r0}h_{sr}(B-B')\geq 0. \tag{19}$$

Therefore, if $p\geq p'$, $q\geq q'$ then $\mathbf{I}(\mathbf{p}(t))\geq\mathbf{I}(\mathbf{p}'(t))$, $\mathbf{I}(\mathbf{q}(t))\geq\mathbf{I}(\mathbf{q}'(t))$. Since all the path gains and the background noises at mobile receivers are positive, the positivity and the monotonicity properties are satisfied.

To prove scalability, we show the (10), (11), and (12) equations, then we bring below easily. Let $\alpha>1$.

$$Bh_sB(\alpha)\left(\alpha A-A(\alpha)\right)+ A(\alpha)q_r(t)h_{r0}h_{sr}A\left(\alpha B-B(\alpha)\right)>0, \tag{20}$$

and

$$\frac{p_s(t)h_s}{q_r(t)}B(\alpha)B\left(\alpha A-A(\alpha)\right)+ p_s(t)h_{r0}h_{sr}A(\alpha)A\left(\alpha B-B(\alpha)\right)>0. \tag{21}$$

Since $\alpha>1$, It is easy to see that $\alpha\mathbf{I}(\mathbf{p}(t))>\mathbf{I}(\alpha\mathbf{p}'(t))$, $\alpha\mathbf{I}(\mathbf{q}(t))>\mathbf{I}(\alpha\mathbf{q}'(t))$, so scalability property is satisfied.

V. Simulation Results

In this section, we provide the simulation results for the amplify and forward relay protocol for cooperative networks. We examine the convergence of power control algorithm for cooperative networks. We first consider a simple two-hop cooperative networks, consisting of four source, four relay and one destination in single-cell system. The sources and a destination are located $100m$ apart, and four relays are distributed in a $100 \times 100m$ square area, and source and relay are in same quadrant become a pair of this simulation, as shown in Fig. 2.

The link gain is modelled as a variable due to path-loss. From [12], link gain for a macro-cell urban environment can be modelled by

$$PL(d) = 38.4 + 35\log_{10}(d)\ dB, \quad \text{for } 50\text{m} < \text{d} < 5\text{km}. \qquad (22)$$

where d is the distance in meter. We assume the link gains between source and relay are fixed during the power control and these are determined by the corresponding node distance. We simulate the system for 100 power control iterations.

Fig. 3 shows the SINR for the four users. In Fig. 3, initially, all users transmit with same power as 200mW, all users have the same target SINR -4.5dB. As can be seen from the graph, the proposed algorithm converges to the fixed point. We note that the transmitted source power of the proposed algorithm converge to the fixed power value, respectively in Fig. 4. The power and hence the SINR of all users converge within 10 iterations.

Next we examine the case which sources control their power and relays control gain simultaneously. The simulation result is shown in Fig. 5 and Fig. 6. In this simulation, we assume all users transmit power with same values 200mW. All users have the same target SINR -4.5dB. Fig. 5 shows the SINR of the four users when source control their power and relay also control their gain same time. In this case, we observe all users converge a fixed point, and this case converge slower than the case of fixed source power and relay gain control.

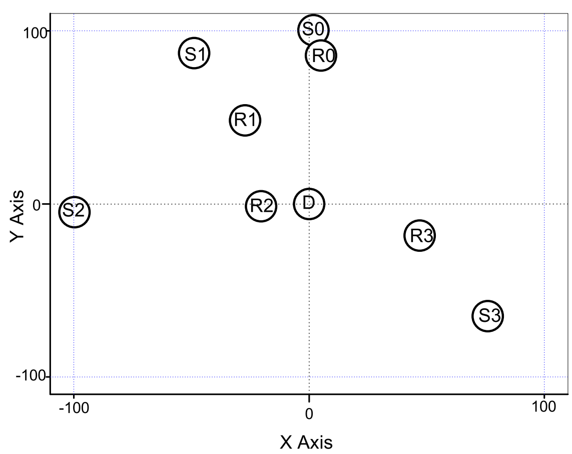

Fig. 2. System set-up for the simulation

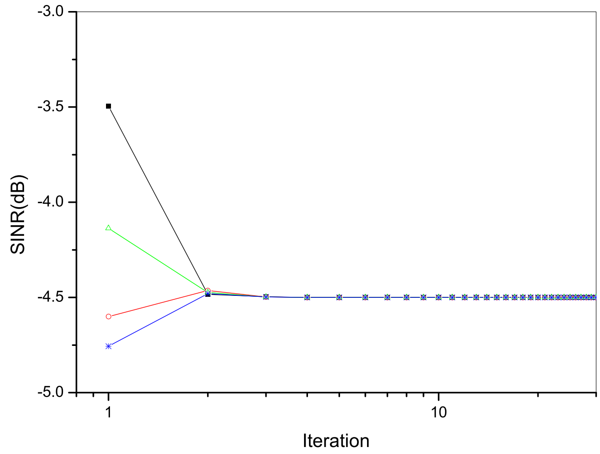

Fig. 3. SINR which source power fixed and relay gain control only

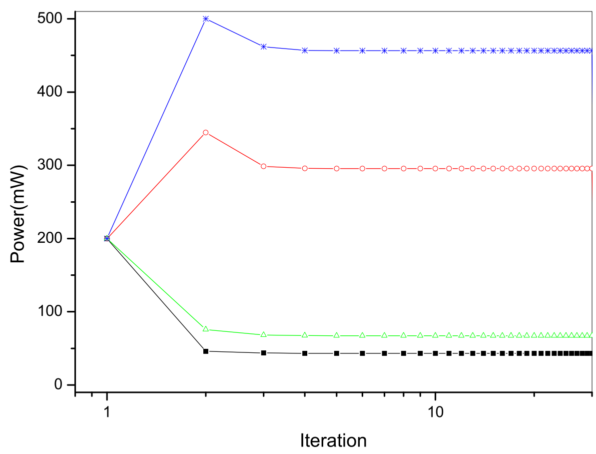

Fig. 4. Source power which source power fixed and relay gain control only

In Fig. 6 show the transmitted power of source. This graphs also show the transmitted source power of the proposed algorithm converge to the fixed power value, respectively. From the graph, we see that convergence of the case of simultaneous control for source power and relay gain is slower than the case of fixed source power and relay gain control.

VI. Conclusion

We propose simple power control algorithms for cooperative networks. We consider two scenarios for cooperative relaying, one is relay gain control only during source power fixed, the other is source power control and relay gain control simultaneously. We show the SINR of the cooperative relaying of the direct link and the relay link, and present the interference function of both cases. We show that the proposed algorithm is a standard so that it converges to a fixed point.

Acknowledgment

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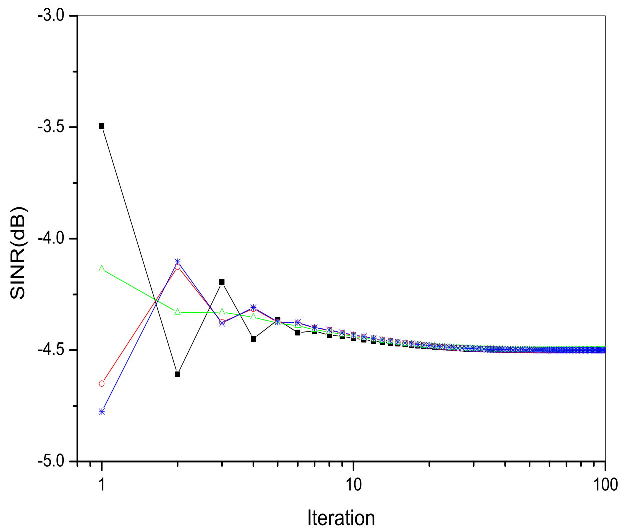

Fig. 5. SINR which source power control and relay gain control simultaneously

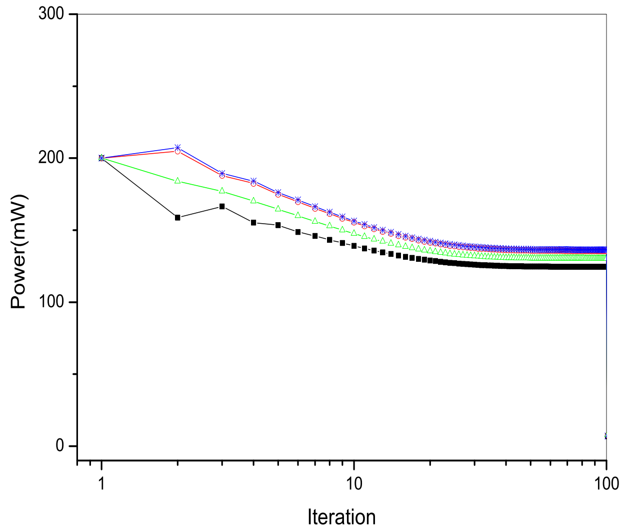

Fig. 6. Source power which source power control and relay gain control simultaneously

REFERENCES

[1] J. Zander, "Performance of optimum transmitter power control in cellular radio systems," *IEEE Trans. Veh. Technol.*, vol. 41. No. 1, pp.57-62, Feb. 1992.

[2] N. Bambos, S. C. Chen, and G. Pottie, "Radio link admission algorithms for wireless networks with power control and active link quality protection," in *IEEE Proc. INFOCOM'95*, Boston, MA, pp.97-104, Apr. 1995.

[3] G. J. Foschini and Z. Miljanic, "A simple distributed autonomous power control algorithm and its convergence," *IEEE Trans. Veh. Technol.*, vol.42, pp. 641-646, Nov. 1993.

[4] D. Kim, "Downlink power allocation and adjustment for CDMA cellular systems," *IEEE Commun. Lett.*, vol. 1, pp. 96-98, Jul. 1997.

[5] D. Kim, "A simple algorithm for adjusting cell-site transmitter power in CDMA cellular systems" *IEEE Trans. Veh. Technol.*, vol. 48, No. 4, pp. 1092-1098, Jul. 1999.

[6] D. Kim, K.-N. Chang, and S. Kim, "Efficient distributed power control for cellular mobile systems," *IEEE Trans. Veh. Technol.*, vol. 46, pp. 313-319, May 1997.

[7] R. D. Yates, "A framework for uplink power control in cellular radio systems," *IEEE J. Select. Areas Commun.*, vol. 13, pp. 1341-1347, Sept. 1995.

[8] C. W. Sung, K. K. Leung., "A generalized framework for distributed power control in wireless networks," *IEEE Trans. Inf. Theory*, vol. 51, Issue 7, pp. 2625-2635, Jul. 2005.

[9] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperative diversity -part I: system description," *IEEE Trans. Commun.*, vol. 51, pp. 1927-1938, Nov. 2003.

[10] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior," *IEEE Trans. Inf. Theory*, vol. 50, pp. 3062-3080, Dec. 2004.

[11] X. Deng, A. M. Haimovich, "Power allocation for cooperative relaying in wireless networks," *IEEE Commun. Lett.*, vol. 9, Issue 11, pp. 994-996, Nov. 2005.

[12] IEEE Standard 802.16j-06, *IEEE Multi-hop Relay System Evaluation Methodology(Channel Model and Performance Metric)*, Feb. 2007