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POWER CONTROL IN CDMA SYSTEMWITH TIME VARYING CHANNEL UNCERTAINTIES-A REVIEW

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ABSTRACT

Power control is used to ensure that each link achieves its target signal-to-interference plus-noise ratio (SINR) to effect communication in the reverse link (uplink) of a wireless cellular communication network. In cellular systems using DS-CDMA, the SINR depends inversely on the power assigned to the other users in the system, creating a nonlinear control problem. The nonlinearity now arises by the uncertain random phenomena across the radio link, causing detrimental effects to the signal power that is desired at the base station. Mobility of the terminals, along with associated random shadowing and multi-path fading present in the radio link, results in uncertainty in the channel parameters. To quantify these effects, a nonlinear MIMO discrete differential equation is built with the SINR of the radio-link as the state to analyze the behavior of the network. Controllers are designed based on analysis of this networked system, and power updates are obtained from the control law. Analysis with Realistic wireless network mobility models are used for simulation and the power control algorithm formulated from the control development is verified on this mobility model for acceptable communication.

Keywords: CDMA, MTP, Multipath fading and channel uncertainties.

I. INTRODUCTION

In mobile communication system the Code Division Multiple Access (CDMA) plays vital role with other present techniques such as Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). The main features of CDMA system for mobile communication applications are the widespread one-cell frequency reuse, intrinsic multipath diversity, and soft capacity limit. To efficiently apply the advantage of CDMA, it is necessary to understand effect of power control on the near-far problem, slow shadow fading and multipath fading [1-2]. The CDMA is based on spread spectrum technology which makes the optimal use of available bandwidth. It allows each user to transmit over the entire frequency spectrum all the time. More security is provided in CDMA technology as a unique code is provided to every user and all the conversation between two users are encoded ensuring a greater level of security for CDMA users.

Various transmitter power control methods have been developed to deliver a desired quality of service (QoS) in wireless networks [1–8]. The concept of Signal-to-Interference (SIR) balancing was introduced in [9] and [10], where all receivers experience the same SIR levels. Maximum achievable SIRs were formulated considering the SIR balancing problem as an eigenvalue problem. A stochastic distributed transmitter power approach was also investigated in [6–8]. Methods were developed to reduce co-channel interference for a givechannel allocation using transmitter power control in [6] and [8].

Radio channel uncertainties, particularly fading, are responsible for the cellular network to be characterized as a nonlinear system. The fading process is characterized as a time-varying stochastic process which is responsible for significant power drops in certain regions known as deep faded regions causing problems in recovering the signal at the receiver.

Of the channel uncertainties, multi-path fading has the most critical effect on the design of a power-control system because of the time and amplitude scales. Multi-path fading is caused by reflections in the environment, which cause multiple time-delayed versions of the transmitted signal to add together at the receiver. The time offsets cause the signals to add with different phases, and thus multi-path fading can change significantly over distance scales as short as a fraction of a wavelength. For instance, for a system using the 900 MHz cellular band, the channel coherence time (the time for which the channel is essentially invariant) for a mobile terminal traveling at 30 miles/hour is approximately 10 ms. There is a need to quantify the multi-path fading effects of the channel in the system. In this thesis, efforts are made to understand the fading phenomena in the radio channel of a CDMA-based cellular communication network and quantify them to develop power control algorithms. The modeling of cellular communication networks is based on analysis of the nonlinear networked system and Lyapunov-based control structures are formulated for such systems in this thesis. An analytical approach to choosing power update sampling time is used in this thesis where channel uncertainties (especially Rayleigh fading) are quantified based on estimation of error between the desired and actual Signal-to-Interference plus Noise Ratio (SINR).

II. SYSTEM STRUCTURE

Designing a perfect radio channel in mobile communications would be practically an impossible task since the channel is stochastic in nature as the mobile terminals keep moving almost all the time with different speeds and the channel fades are unpredictable. The signals in a radio channel undergo different propagation effects like reflection, refraction, scattering and shadowing. A smooth surface reflects the signals. But, when the signals encounter sharp edges of buildings, they are refracted, while a rough surface scatters them. When these signals are obstructed by big buildings, they pass through them causing the shadowing effect. All these effects cause the channel to be lognormal, Rayleigh and Rician distributed. Fig.1 shows how the signals travel in different paths from transmitter to receiver. So, the receiver receives multiple copies of the same signal with variation in time and phase. These signals are either added constructively or destructively depending on the phase of the signals.

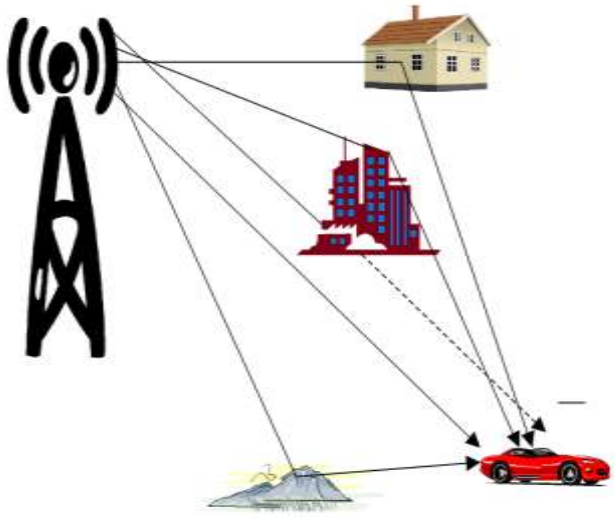

Fig.1: Multipath Propagation

The signals in the radio channel also undergo a path loss which depends on the distance between the transmitter and the receiver. The fading of signals is categorized as fast or multi-path fading and slow or shadow fading. The fast fading of signals is due to the rapid change of the signal amplitude and phase due to the multi-path arrival of the signal. Similarly, the slow fading of the signals is due to the hadowing ffects caused by the buildings, mountains, etc.

CHANNEL MODELING

The characteristics of the reverse link of the radio channel investigated and modeled. The channel gain of a radio link (Figure 2-1) is comprised of three components: Exponential path-loss, Log-normal shadowing, and Multi-path fading. The gain of the channel is defined [18] as

$$g_{ii}(l) = g_{do}\left(\frac{d_i(l)}{d_o}\right)^{-k} 10^{0.1\delta i(l)}|x_i(l)|^2 \qquad \textbf{(1)}$$

Where the term | X where the term | Xi(l)|^2 is used to model Rayleigh fading., g_{do} is the near-field gain given by [11]

$$g_{do} = \frac{G_t G_r \lambda^2}{(4\pi)^2 d_n^2 L}, \qquad d_f \le d_o \le d_i(l) \qquad \textbf{(2)}$$

Where G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the wavelength in meters, L is the system-loss factor, d0 is the distance between the transmitter and receiver antenna, and d_f= 6m is the Fraunhofer distance. Without loss of generality, Gt, G, and L are all assumed to be 1. Since the power updates are provided at discrete instances due to bandwidth constraints, the system is analyzed at discrete instances of time (l ∈ Z). For this reason, the continuous time channel parameters are analyzed and a suitable channel sampling time is chosen.

The term $\left(\frac{d_i(l)}{d_o}\right)^{-k}$

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is used to model the average path loss at distance $d_i(l)$ from mobile terminal (MT) to the base station (BS), where κ is the path-loss exponent, which typically takes values between two and five. The term $10^{0.1\delta i\,(l)}$ is used to model large-scale log-normal shadowing from buildings, terrain, or foliage, where $\delta i\,(l)$ is a Gaussian random process (see [11]).

When a MT communicating with a BS, the received signal at the BS is faded due to the mobility of the MTs causing doppler shifts in the frequency of the received wave and multipath propagation of the wave caused by scattering in the presence of surrounding objects. These individual components add up in a constructive or destructive manner, depending on random phase shifts of these components of the received signal. The received fading component of the signal can be represented as [19]

$$X_i(t) = G_c(t)\cos(2\pi fct) - G_s(t)\sin(2\pi fct) \quad (3)$$

Where f_c is the carrier frequency, the Gaussian random processes $G_c(t)$ and $G_s(t)$ are defined as

$$G_c(t) = E_0 \sum_{n=1}^{N} C_n \cos(2\pi f_n t + \emptyset_n) \quad (4)$$

$$G_s(t) = E_0 \sum_{n=1}^{N} C_n \sin(2\pi f_n t + \emptyset_n) \quad (5)$$

The processes $G_c(t)$ and Gs(t) are uncorrelated zero-mean Gaussian random variables for any t with equal variance $E_0^2/2$, where E_0 is the real amplitude of the local average E-field (assumed constant), Cn is the real random variable representing the amplitude of individual waves, Φ_n is the phase shift due to reflections of the individual waves and is an uniform random variable in [0,2P], N is the number of scattered waves, and fn(t) is the doppler frequency defined as

$$f_n = \frac{v}{\lambda} cos\theta \quad (6)$$

In this equation, v(t) is the velocity of motion of the MT and θ(t) is the angle between the transmitted signal and the direction of motion of the MT.

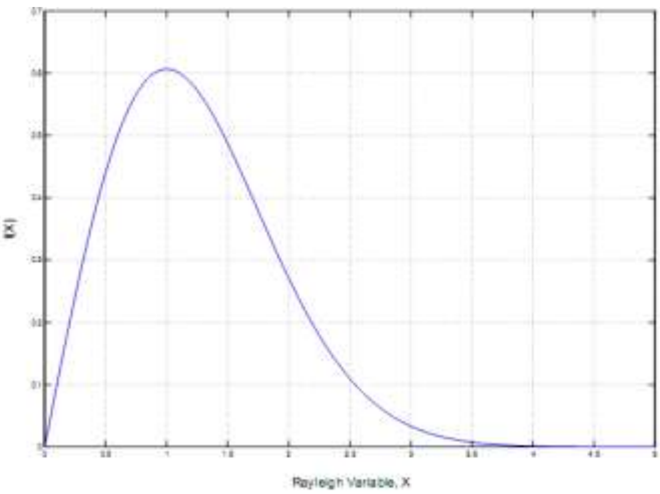

Fig. 2. Probability density function of a Rayleigh random variable.

The envelope of the received signal (E-field) is

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$$|x_i(t)| = \sqrt{G_c{}^2(t) + G_s{}^2(t)} \qquad (7)$$

where |X(t)| is a random variable with a Rayleigh distribution with a probability density function of (refer to Figure 2)

$$P(|X_i|) = \frac{X_i}{\frac{E_0^2}{2}} \exp\left(\frac{X_i}{2\left(\frac{E_0^2}{2}\right)}\right), \qquad 0 \le X_i \le \infty \quad = \quad 0, \qquad X_i < 0 \qquad (8)$$

Squaring Equation 7 yields the fading power, i.e.

$$|X_i(t)|^2 = G_c^2(t) + G_s^2(t) \qquad (9)$$

The power of the received envelope for a faded radio channel (Doppler frequency = 10Hz) is shown in Figure 3.

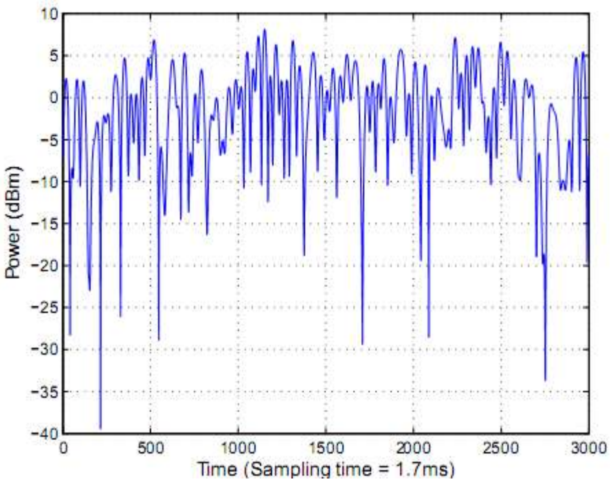

Fig. 3. Power of the received envelope or a 10Hz fading channel.

For analytical purposes, $X_i(t)$ is usually taken to be a complex-valued Gaussian random process, and thus | X(t)| is a Rayleigh random variable for each t when E[X(t)] = 0 (the operator E[X] is used to represent the expected value of a random variable X), which corresponds to no line-of-sight path from the MT to the BS. Gaussian random processes provide good models for the log-normal shadowing and Rayleigh fading over the most-probable range of reception. However, both of these processes are unbounded, which means that any received power level is possible. However, gii(l) cannot take arbitrarily large values in practice because the received power cannot exceed the transmitted power. Furthermore, a communication system cannot practically transmit to overfaded users who are in very deep fades (i.e., when gii(l) is close to zero) because doing so would require extremely large power at that user and the other users (because the power transmitted to each user causes interference at the other users) [12]. Hence, the subsequent development is based on the assumption that the fading power |Xi(·)|^2 is bounded and non-zero.

The development in this paper considers the reverse channel (from the MTs to the BS) and investigates control of the SINRs for the MTs. The SINR at MT i, denoted by $X_i(l) \in R$, can be expressed as [13]

$$X_i(l) = \frac{a g_{ii}(l) p_i(l)}{I_i(l)} \qquad \textbf{(10)}$$

Where $P_i(l) \in R$ is the power from the MT i to the BS, and $g_{ii}(l) \in R$ is the channel gain from the BS to the MT i. In Equation 10, $I_i(l) \in R$ denotes the interference-plus-noise power at the BS due to transmissions by other MTs in the cellular network, defined as

$$I_i(l) = \sum_{j \neq i} g_{ij}(l)\, p_j(l) + a n_i \qquad \textbf{(11)}$$

where $g_{ij}(l) \in R$ is the channel gain for the link between MT j and the BS that affects the interference in the radio link between MT i and the BS, $p_j(l) \in R$ is the power transmitted by MT j to the BS, and $n_i \in R$ denotes the thermal noise in link i. In a CDMA based network, each radio link is forced to share the same bandwidth; hence, Ii(•) is non-zero and bounded. The bandwidth spreading factor, or the processing gain [14] for the cellular system using CDMA is denoted by a defined as

$$a = \frac{W}{R} \qquad \textbf{(12)}$$

where W is the transmission bandwidth, in hertz, and R is the data rate in bits/second. By increasing the bandwidth spreading factor, the interference of the system can be reduced. Therefore, focus is laid on the effects of fading in the radio channel in this thesis to develop power controllers for radio links operating in a CDMA based cellular communication network. The first difference of the SINR defined in Equation 10 can be determined as

$$\Delta X_i(l) = a(I_i(l) + \Delta I_i(l))^{-1} \frac{\Delta g_{ii}(l)}{T_s} p_i(l) \; + \\ a I_i(l) + \Delta I_i(l)^{-1} \Delta g_{ii}(l) \frac{\Delta P_i(l)}{T_s} \; - \\ \{ I_i(l)(I_i(l) \; + \\ \Delta I_i(l)^{-1}\}^{-1} \left\{ a \sum_{j \neq i} (\frac{\Delta g_{ii}(l) p_i(l)}{T_s}) g_{ii}(l) p_i(l) + \\ a \sum_{j \neq i} (\frac{g_{ii}(l) p_i(l)}{T_s}) g_{ii}(l) p_i(l) \right\} + \\ \left[\left\{ a\, I_i(l)(I_i(l) + \Delta I_i(l)^{-1^{-1}} \frac{\Delta g_{ii}(l)}{T_s} \frac{\Delta P_i(l)}{T_s} \right\} - \\ a \sum_{j \neq i} (\frac{\Delta g_{ij}(l) p_j(l)}{T_s^2}) g_{ii}(l) p_i(l) - \{ (I_i(l)(I_i(l) + \\ \Delta I_i(l))^{-1} g_{ii}(l) p_i(l)_i \right]$$

(13)

Where Equation 10 and Equation 11 were used, and Ts is the power update interval. Neglecting the residual terms in square brackets in Equation 13, approximating

$$\{(I_i(l) + \Delta I_i(l)\} \cong I_i(l)$$

and using Equation 10 yields

$$X_i(l+1) = \alpha_i(l,x)x_i(i) + u_i(l) \quad \textbf{(14)}$$

Where $x_i(l,x) \in R$ is an unknown, time-varying state-dependent quantity, defined as

$$\alpha_i(l,x) = ag_{ii}(l+1)g_{ii}^{-1}(l) - a\left(\sum_{i\neq j}\Delta g_{ii}(l)p_j(l)\right)I_i^{-1}(l) - a\left(\sum_{i\neq j}g_{ii}(l)\Delta p_j(l)\right)I_i^{-1}(l) \quad \textbf{(15)}$$

and $u_i(l) \in R$ is the control input, defined as

$$u_i(l) = \frac{x_i(l)}{p_i(l)}[P_i(l+1) - P_i(l)] \quad \textbf{(16)}$$

$$X_i(l+1) = \alpha_i(l,x)X_i(l) + u_i(l) + \xi_i(l,x) \quad \textbf{(17)}$$

By defining the interference $I(l) \in R^{nxn}$ as a diagonal matrix with entries $I_i(l)$ expressed in Equation 11, $g(l) \in R^{n\times n}$ as a diagonal matrix with entries $g_{ii}(l)$, and $P(l) \in R^n$, then the MIMO system can be developed as

$$X(l+1) = \alpha(l,x)X(l) + u(l) + \xi(l,x) \quad \textbf{(18)}$$

Where $\alpha(l,x) = diag(\alpha_i(l,x)) \epsilon R^{nxn}$ denotes the unknown, time-varying state-dependent diagonal matrix (since $\alpha_i(l,x)$ is a function of the state $x_i(l)$ as shown in the Equation (15) which can be assumed to be upper bounded by a known positive constant from the preceding discussion on the uncertain channel parameters, $x(l) \in R^n$ is the state vector at instant l, $u(l) \in R^n$ is the control input vector, $x(l+1) \in R^n$ is the state vector at instant $l+1$, and $\xi(l, x) \in R^n$ is the stochastic measurement noise bounded by a known constant. The measurement noise is assumed to be bounded by a positive constant.

Here, $u(l)$ is expressed in terms of the power update law as

$$P_i(l+1) = \frac{u_i(l)}{x_i(l)}P_i(l) + P_i(l) \quad \textbf{(19)}$$

III. POWER CONTROL

The objective of this paper is to design and analyze the performance of a controller for use in a radio channel operating in a CDMA communication system with Rayleigh fading following Clarke's model [15]. The Rayleigh fading process produces unbounded changes in the SINRs with non-zero probability, even for arbitrarily short time scales, but by using the concept of over faded users [12], the channel gains can be bounded. Based on this model, a simple proportional controller to minimize the sampled SINR error is developed in this chapter. Specifically, despite uncertainty in the multi-path fading effects, a Lyapunov-based analysis is used to develop an ultimate bound for the sampled SINR error which is a function of the upper bound on the channel uncertainty divided by a nonlinear damping gain that can be made arbitrarily large up to some upper value dictated by the power update law. The performance of this controller is evaluated in this chapter via simulation under realistic power limits and channel changes based on the standard random-waypoint mobility model. A statistical analysis of the performance effects of fading between the sampling intervals is considered in this chapter, which is used to discuss the choice of the control update rate. Additional analysis is provided to conclude that the expected value of the squared norm of the SINR error converges to an ultimate bound that is a function of sampling rate. Therefore, the sampling rate can be adjusted to keep the SINR error within a desired range that allows for signal decoding. Simulation results are provided for a Random-Waypoint model that illustrates the performance of the developed controller.

Control Development:

The SINR should remain between two thresholds as

$$\gamma_{min} \leq x_i \leq \gamma_{max} \qquad (20)$$

to achieve acceptable communication performance over the link while minimizing interference to adjacent cells. The control objective for the following development is to regulate the SINR to a target value for each channel, denoted by $\gamma \in R^n$, while ensuring that the SINR remains between the specified lower and upper limits for each channel, as described in Equation 20. To quantify the objective, a regulation error $e(l) \in R^n$ is defined as

$$e(l) = x(l) - \gamma \qquad (21)$$

Closed-Loop Error System:

The first difference of the regulation error, denoted as $e(l) \in R^n$, is

$$(l) = e(l+1) - e(l) = x(l+1)x(l)$$
$$= \alpha(x,l)x(l) + u(l) + \epsilon(l,x) - x(l) \; (22)$$

To facilitate the subsequent analysis, the expression in Equation 22 is rewritten as

$$\Delta e(l) = X(l,x) + \Omega(\mathrm{l},\mathrm{x}) + \mathrm{u}(l) \qquad (23)$$

Where $X(l,x) \in R^n$ denotes an auxiliary term defined as

$$X(l,x) = \left(\alpha(l,x) - I^{nx1}\right)e(l) \qquad (24)$$

and $\Omega(\mathrm{l},\mathrm{x}) \in \mathrm{R}^n$ is defined as

$$\Omega(l,x) = \left(\alpha(l,x) - I^{nx1}\right)\gamma + \xi(l,x) \qquad (25)$$

Motivation for introducing the auxiliary terms in Equation 24 and Equation 25 is to collect terms that have a common upper bound. Specifically, upper bounds for $X(l,x)$ and $\Omega(\mathrm{l},\mathrm{x})$ can be developed as

$$||\mathbf{X}(\mathbf{l},\mathbf{x}))|| \leq \mathbf{c_1}||\mathbf{e}(\mathbf{l})|| \;\; \mathbf{and}||\boldsymbol{\Omega}(\mathbf{l},\mathbf{x}))|| \leq \mathbf{c_2} \qquad (26)$$

where c1, c2 $\in$ R denote known positive constants. Based on Equation 23, Equation 26, and the subsequent stability analysis, a proportional controller is designed as

$$\mathrm{u}(l) \triangleq -(c_1 + k_n + k_1)e(l) \qquad (27)$$

Where c_1 is introduced in Equation 26, and $k_n, k_1 \in R$ denote positive control gains.

Based on Equation 19 and Equation 27, the power update law is

$$P_i(l+1) = \frac{-(c_1+k_n+k_1)e_i(l)P_i(l)}{e_i(l)+\gamma} + P_i(l) \quad (28)$$

under the constraint that $0 \leq P_i(l) \leq P_{max}$ where P_{max} is a maximum power level. After substituting Equation 27 into Equation 23, the closed-loop error system for e(l) can be determined as

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$$\Delta e(l) = X(l,x) + \Omega(\mathrm{l},\mathrm{x}) + \mathrm{u}(l) - (c_1 + k_n + k_1)e(l) \quad \textbf{(29)}$$

IV SIMULATION AND RESULTs

All simulations for communications channels in CDMA system topology was built in MATLAB, and the mobility of the MTs are modeled by a steady state distribution model (i.e., [16], [17]). The error signal is expressed as

$$e_{idB}(l) = 10log\frac{x_i(l)}{\gamma}\,DB \qquad \textbf{(30)}$$

Where $\gamma = 8DB$ is the target SINR with a range between 6 and 10dB. Thermal noise, η is set to −110dBm.

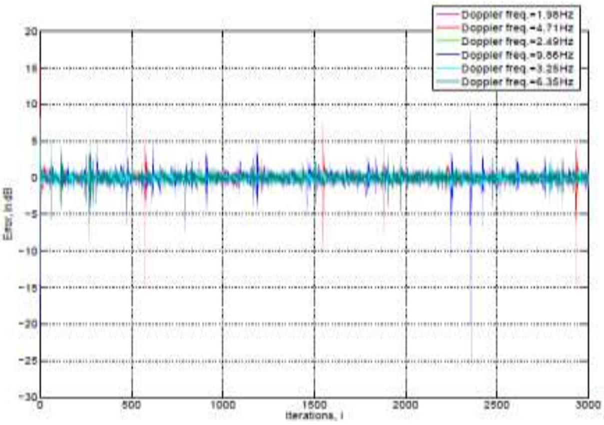

Fig. 4. Error plot: MTs with low dopple frequencies.

A Rayleigh faded channel is created using the channel sampling time of 1.7ms obtained from the error analysis and the Doppler frequency, given in Equation 6, where λ= 0.33m is the wavelength of the signal. The probability density function of the velocity is given by [17]

$$f_i(v) = \frac{C_h}{v} f^0_{v|h}(v) \qquad \textbf{(31)}$$

where

$$f^0_{v|h}(v) = \frac{1}{v_{max} - v_{min}}$$

$$= \frac{1}{\frac{48km}{hr} - 2km/hr} = \frac{1}{46km/hr}$$

is a classical choice for the density of the velocity, and Ch = 14.47 is the normalizing constant. The subscript h is used to denote the phase of the MT [17]. The velocity for each of the MTs is obtained from Equation 31 using the inverse transform method as

v=exp(3.179r + 0.6931) (32)

where r is uniformly distributed between 0 and 1. The Doppler frequency is obtained from Equation 32 and by measuring θ periodically. measuring θ periodically. Path loss, with free space propagation effects (near-field effects), and log-normal shadowing are modeled [11] as shown in Equation 1 and Equation 2.

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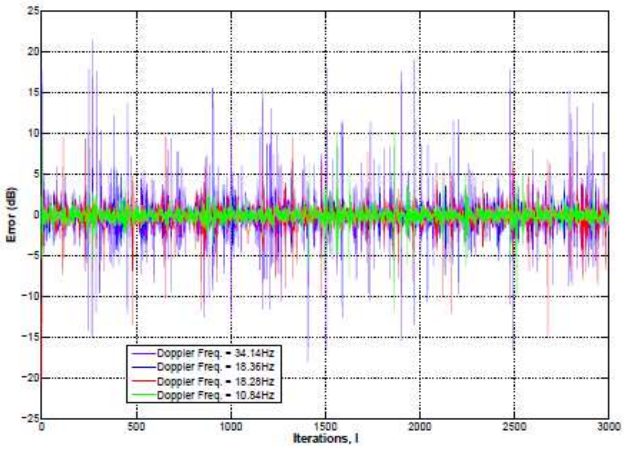

Fig.5. Error plot: MTs with high Doppler frequencies.

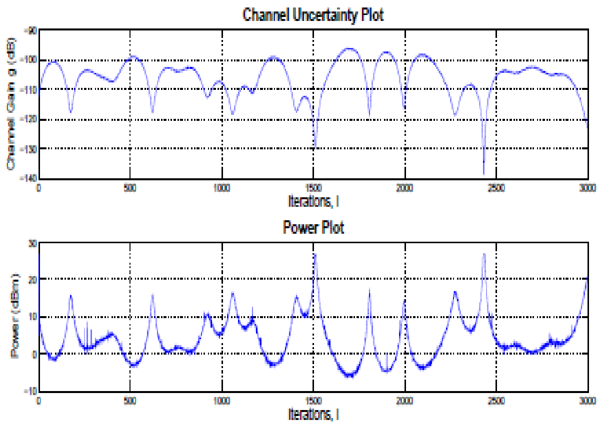

Fig 6. channel gain and power plot: MT with a doppler frequency of 1.98 Hz.

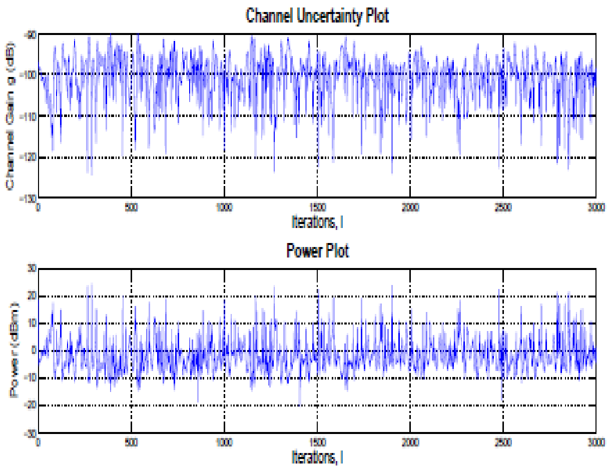

Figure 7. channel gain and power plot: MT with a doppler frequency of 34.14 Hz.

V. CONCLUSION

Radio channel uncertainties, particularly fading, are responsible for the cellular network to be characterized as a nonlinear system. The fading process is characterized as a time-varying stochastic process which is responsible for significant power drops in certain regions known as deep faded regions causing problems in recovering the signal at the receiver. Further, restrictions in the maximum power at which the signals can be transmitted in such systems and bandwidth availability intensifies the need to develop power controllers for such radio links. To address these problems, controllers are designed that uses the Lyapunov-based tools to analyze the nonlinear system, and the simulation results are discussed to demonstrate and validate the theory behind the control design.

A robust power controller is developed for a wireless CDMA-based cellular network system. Lyapunov-based stability analysis is used to develop an ultimate bound for the sampled SINR error which can be decreased up to a point by increasing a nonlinear damping gain. An analysis is also provided to illustrate how mobility and the desired SINR regulation range affects the choice of channel update times. The choice of the update time also affects the ultimate bound that the sampled SINR error reaches - Lowering the sampling time reduces the ultimate bound. Simulations indicate that the

SINRs of radio links operating with lower maximum Doppler frequency are maintained in the desired communication range. Radio links operating with a high maximum Doppler frequency have high outage probability due to the fastly time-varying nature of the channel uncertainties, and this motivated to use the concept of prediction to address the issue.

REFERENCES

[1] N. Bambos, S. Chen, and G. Pottie, “Channel access algorithms with active link protection for wireless communication networks with power control,” IEEE/ACM Trans. Networking, no. 5, pp. 583–597, 2000.

[2] G. Foschini and Z. Miljanic, “A simple distributed autonomous power control algorithm and its convergence,” IEEE Tran. Veh. Technol., vol. 42, pp. 641–646, 1993.

[3] S. Grandhi and J. Zander, “Constrained power control in cellular radio systems,” in Vehicular Technology Conference, 1994 IEEE 44th, 8-10 June 1994, pp. 824–828vol.2.

[4] R. Jantti and S. Kim, “Second-order power control with asymptotically fast convergence,” IEEE J. Select. Commun, vol. 18, no. 3, 2000.

[5] 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.

[6 J. Zander, “Optimum global transmitter power control in cellular radio systems,” in IEEE Int. Symp. on Personal, Indoor and Mobile Radio Commun., London, U.K., 1991.

[7] “Distributed cochannel interference control in cellular radio systems,” IEEE Tran. Veh. Technol., vol. 41, pp. 305–311, 1992.

[8] “Performance of optimum transmitter power control in cellular radio systems,” IEEE Trans. Veh. Technol., vol. 41, pp. 57–62, 1992.

[9] J. Aein, “Power balancing in systems employing frequency reuse,” COMSAT Tech. Rev., pp. 277–299, 1973.

[10] H. Alavi and R. Nettleton, "Downstream power control for a spread spectrum cellular mobile radio system," in Proc. IEEE GLOBECOM, 1982, pp. 84–88.

[11] T. Rappaport, Wireless Communications, Principles and Practice. Prentice Hall, 1999.

[12] L. Gao and T. Wong, "Power control and spreading sequence allocation in a cdma forward link," IEEE Trans. Inform. Theory, vol. 50, no. 1, pp. 105–124, Jan. 2004.

[13] N. Bambos, "Towards power-sensitive network architechtures in wireless communications: Concepts, issues and design aspects," IEEE Pers. Commun., pp. 50–59, 1998.

[14] A. J. Viterbi, CDMA: Principles of Spread Spectrum Communication. Addison Wesley, 1995.

[15] R. H. Clarke, "A statistical theory of mobile-radio reception," Bell Syst. Technical J., vol. 47, no. 6, pp. 957–1000, Jul.–Aug. 1968.

[16] S. Pal Chaudhuri, J.-Y. Le Boudec, and M. Vojnovic, "Perfect simulations for random trip mobility models," in Simulation Symposium, 2005. Proceedings. 38th Annual, 4-6 April 2005, pp. 72–79.

[17] J.-Y. Le Boudec and M. Vojnovic, "Perfect simulation and stationarity of a class of mobility models," in INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE, vol. 4, 13-17 March 2005, pp. 2743–2754vol.4.