Transmit Power Control in Fixed Cellular Broadband Wireless Systems

Salem Salamah, David D. Falconer and H. Yanikomeroglu
Department of Systems and Computer Engineering
Carleton University
Ottawa, Ontario, Canada K1S 5B6

ABSTRACT - **Local Multipoint Communication Services (LMCS) refer to millimeter-wave point-to-multipoint access systems that provide broadband services to both residential and commercial subscribers. Coverage is the most important problem to be resolved for the successful deployment of the LMCS systems. This paper reports the performance study of LMCS in relation to transmit power control. An extensive simulation model has been used to study the effects of a number of factors on the system outage performance. These factors include the propagation model, power control command rate, step size and dynamic range.**

I. INTRODUCTION

Cellular fixed broadband access system has been proposed in the frequency range of 28 GHz in order to provide broadband services, such as cable TV, video conferencing, internet access and various multimedia services, for homes and business subscribers [1,2].

In the frequency range of 28 GHz the wavelength is in the order of one centimeter. With such a small wavelength, trees, buildings, terrain and even rain drops cause significant attenuation, and this results in a coverage problem.

In this paper, we make the following contributions. First, using power control (PC) we evaluate the system availability in the presence of Rician fading and log-normal shadowing. Second, we study the dependence of performance on the propagation parameters. In particular, we consider the case in which intended subscriber and the interferers undergo different impairments. Finally, optimum PC step size and command rate are determined in a given environment.

II. SIMULATION MODEL

We consider a cellular LMCS system where the entire frequency band is reused in each sector, through the employment of highly directional antennas and perfect orthogonal polarization in adjacent sectors. We consider a service area composed of 9 cells, each with 4 sectors, as shown in Fig. 1 (V and H denote the vertical and horizontal frequency polarization, respectively). The distance between base stations is 4 kms, which gives a total coverage area of 144 km^2.

The large-scale variation (shadowing) is represented by a lognormal random variable *Z* expressed in dB with zero mean and a certain standard deviation. Also, fast fading is included in our model through a Rician r.v. β with probability distribution function (pdf):

$$P(\beta) = \frac{\beta}{\sigma^2} \exp\left(-\frac{\beta^2+A^2}{2\sigma^2}\right) I_0\left(\frac{A\beta}{\sigma^2}\right), \qquad (1)$$

where $I_o(.)$ is the modified Bessel function of the first kind and of zeroth order.

A channel that is time correlated is developed to provide a more realistic analysis compared to an independent fading channel. The time correlation is implemented using a first-order auto-regressive process by passing the Gaussian r.v's that generate the Rician r.v through a lowpass filter as shown in Fig.2. Then, the correlated Gaussian r.v can be represented as follows [3]:

$$U_{Xm+1} = \alpha * U_{Xm} + (1-\alpha) * X_m \qquad (2)$$

$$U_{Ym+1} = \alpha * U_{Ym} + (1-\alpha) * Y_m \qquad (3)$$

where $\{X_m\}$ and $\{Y_m\}$ denote independent, identically distributed Gaussian sequences with zero mean and standard deviation σ. $\{U_{Xm}\}$ and $\{U_{Ym}\}$ are the time correlated Gaussian sequences. In the above, α denotes the correlation factor; if $\alpha=0$ then the samples are uncorrelated and if $\alpha=1$ the time samples are identical. Then, the Rician r.v. β_m, is

$$\beta_m = \sqrt{\left(A+U_{X_m}\right)^2 + U_{Y_m}^2} \qquad (4)$$

The time constant of the lowpass filter is $1/(1-\alpha)$. After a few time constants, the steady-state is reached. Let σu denote the standard deviation of the time correlated Gaussian sequences at the steady-state. It can be shown from Eqn.s 2 and 3 that

$$\sigma_U{}^2 = \frac{1-\alpha}{1+\alpha}\sigma^2 . \qquad (5)$$

Without loss of generality, we set the average fading power at steady state to unity:

$$E(\beta_m^2) = 2\sigma_U^2 + A^2 = 1. \tag{6}$$

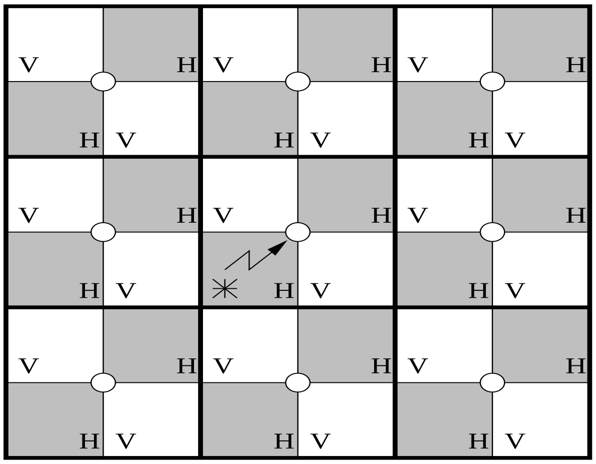

Fig. 1: LMCS System Model

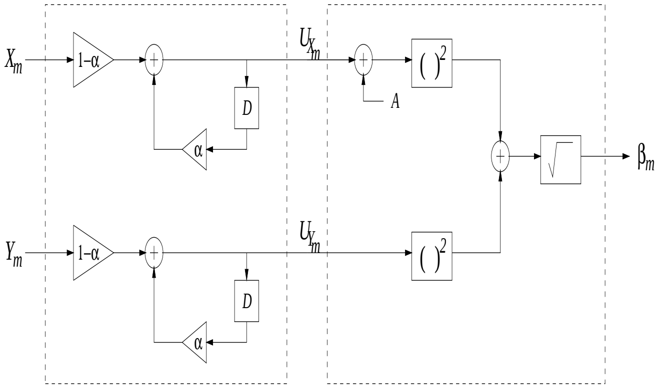

Fig. 2: Auto-regression process with lowpass filtering

The Rician *K* factor is defined as the ratio of the power of the LOS component to that of the scattered component:

$$K = \frac{A^2}{2\sigma_U^2}\cdot \tag{7}$$

It can be shown from Eqn.s (6) and (7) that

$$\sigma_U^2 = \frac{1}{2K+2}\cdot \tag{8}$$

Then, it follows from Eqn.s (5) and (8) that

$$\sigma^2 = \frac{1}{2K+2}\frac{1+\alpha}{1-\alpha}\cdot \tag{9}$$

Now the received power at the base station corresponding to the i^{th} user can be expressed as: [4]

$$S_i = P_T G_T G_R \left(\frac{c}{4\pi f d_o}\right)^2 \left(\frac{d_o}{d}\right)^n 10^{\frac{Z}{10}} \beta^2, \tag{10}$$

where P_T is the transmitted power of the subscriber, *n* is the propagation exponent, G_T and G_R are the transmitter and receiver antenna gains, *f* is the carrier frequency in Hz, *c* is the speed of light ($3*10^8$ m/sec), and d_0 is the reference distance which is taken to be 20 m.

Then the signal-to-interference-plus -noise ratio (SINR) for user *i*, γ_i , can be calculated as follows;

$$\gamma_i = \frac{S_i}{\sum_{j=1, i\neq j}^{18} I_j + N_u} \tag{11}$$

where N_u refers to the thermal noise for an uplink channel of 2 MHz, and I_j to the interference from user *j*.

Outage probability is a useful performance measure, expressing the fraction of time that the signal-to-interference ratio is below a certain threshold γ_s due to fading, for a given desired user in a given position:

$$P_{outage}(\gamma_s) = \Pr\{\gamma < \gamma_s\}. \tag{12}$$

System availability can be defined as the percentage of subscribers that have an outage probability of 1% or less.

III. SIMULATION ALGORITHM

SINR-based PC [5,6] is employed in the simulations. We consider only the reverse link. It is reported in earlier studies that PC for LMCS can results in two to three fold improvement in system outage [7].

In our simulations, PC is applied for the entire system. However, the data is collected only from users within the first sector of central cell to avoid boundary effects.

The simulation results indicate that the dominant interferer is the one that is located in the same cell, but in the opposite sector, with the desired user. It is logical to expect that this dominant interferer will statistically have the same channel characteristics as the desired user. This point is taken into consideration in the simulations and the propagation parameters of the dominant interferer are always taken to be the same as those of the desired user. So when we refer to the propagation parameters of the interferers, they are always for the other interferers, not for the dominant one.

The framework of the simulation program is given below:

Step 0: Set up system parameters

- Set up system parameters such as cell radius, channel bandwidth, antenna gains and beamwidths.
- Set up the propagation exponent, Rician *K* factor, and lognormal shadowing for the desired user and the dominant interferer. Other interferers will have different propagation parameters. Also set the correlation factor α.
- Set up the PC parameters such as the outer loop threshold (γ_{th} = 15 dB), number of samples per location, PC step size and number of locations.
- Set up the target SINR for the outage probability calculation.

Step 1: Initialization

- Generate users with a uniform distribution within each sector.
- For each user, set up an independent lognormal distributed shadowing on its corresponding downlink, each subscriber will calculate the received SINR from the different base stations and then assign the user to the base station with the best SINR (i.e. macrodiversity).
- Set an initial transmit power level for each user; all users start simulation with P_T = - 20 dBw.

Step 2: Simulation over an observation period.

- Set up a Rician channel between each user and its base station. As explained in Section II, the fading samples are correlated in time. For each fading sample, the system is frozen and PC algorithm is executed in the entire system as follows:

Measure the received SINR from the desired user at the base station, compare it with γ_{th}, and adjust the transmit power by a fixed step size Δ (dB) as follows:

$$P_{m+1} = \begin{cases} P_m + \Delta & if\, \gamma \le \gamma_{th} \\ P_m - \Delta & if\, \gamma > \gamma_{th} \end{cases} \qquad (13)$$

where P_m is the current power level and P_{m+1} is the updated one.

- For each snapshot (frozen system) execute a preset number of PC commands. For instance, for PC/snapshot=10, the base station issues 10 PC commands to the subscriber while the system is frozen.
- Collect a preset number of fading samples (snapshots).
- Calculate the outage probability for the desired user. We assume γ_s =10 dB.

Step 3: Repeat the simulation cycle.

- Go to step 1 unless number of locations exceeds the preset value chosen as 1000 location.

The system stability was carefully studied, and tests were carried out to confirm whether the system ever becomes unstable. We noticed that the system always reached steady state within 40 samples. In order to avoid the bias in the results, the startup period data is excluded from our results.

IV. RESULTS

In Fig.s 3-6, n_d , n_i , K_d , K_i denote the propagation exponents and the Rician *K* factors of the desired user (and the dominant interferer) and the other interfering users, respectively.

- The effect of the desired subscriber propagation exponent on system availability is shown in Fig. 3. It is observed that a small propagation exponent for the desired subscriber yields a lower outage probability and thus a significant increase in system availability; for instance, using a power control-to-snapshot ratio of 10 and a PC step size of 2 dB, a system availability of 0.71 can be achieved for n_d = 2. If n_d is increased to 3 and to 4, the system availability reduces to 0.46 and to 0.31, respectively. In Fig. 3 the interferer propagation exponent, n_i is kept at 4.

- In Fig. 4, we show the system availability as a function of n_i . We fix n_d =2. It is observed that the system availability increases significantly from 0.47 to 0.71 when n_i increases from 2 to 4 for the case of PC/snapshot =10. Since higher values of propagation exponent for out of cell intereferers leads to more attenuation to their signal, this yields a higher SINR for the desired user. Therefore, the outage probability for the desired subscriber would benefit from the high attenuation of the interfering signals, and thus be reduced, which enhances the availability in the system.

- Fig. 5 shows the effect of PC on system availability. It is observed that for the case of PC/snapshot=1, the system availability degrades even more as the step size is increased.

PC/snapshot=10 with a step size of 2-3 dB will slightly improve the system availability; further increase of the power control step size will degrade the system performance. Increasing Δ will degrade the system availability because if the received SINR reaches the system threshold, there is no do nothing command, so higher step size will effect the outage probability of the subscriber. The higher the PC/snapshot rate the better the system performance will be for small Δ.

PC/snapshot of 30 and 50 shows a further improvement in system availability compared to a PC/snapshot ratio of 10. At higher PC/snapshot ratio the power control step size can be reduced while still giving a better availability, e.g. PC/snapshot =100 and power step size of 0.5dB.

Note that the upper curve in Fig. 5 represents the system availability due solely to shadowing and path loss. In this case, the system availability is improved by 15% even in the case of no power control.

- The effect of the transmitted power dynamic range on system availability is shown in Fig. 6. It is observed from this figure that the value of the upper bound of the transmitted power is very important. This is due to the fact that, no upper bound for P_t will allow subscribers with high outage probability, to increase their transmitted power to satisfy the SINR requirement by the base station, which in turn cause severe interference to other subscribers. At the same time, other subscribers will increase their transmitted power to keep the quality of signal at a certain acceptable level and this positive feedback will destroy the overall performance. In Fig. 6, it is observed that removing the lower bound restriction on the subscriber transmitted power will give a further improvement in the system availability, since no lower bound condition on the transmitted power allow subscribers to reduce their transmitted power if the service requirement by the hub is satisfied. This reduction in transmitted power will reduce the interference to other subscribers and enhance the overall system performance. On the other hand, if the upper bound condition on the transmitted power is released, the system availability will be degraded to 0.79 at an outage probability of 1%.

The PC/snapshot rate can be related to the PC update rate per 3-dB fading bandwidth as follows: we will calculate the power spectral density for the Rician channel by taking Fourier transform of the autocorrelation function of the fading channel β. It can be shown from Fig. 7 that the 3-dB fading bandwidth is 15/snapshot. Then, for example in the case of 30 PC commands per snapshot, the ratio of the PC update rate to the 3-dB fading bandwidth is 2.

VI. CONCLUSIONS

In this paper, we study the system availability for LMCS systems using SINR based PC. Particular attention has been given to the propagation and PC parameters and their impact on the system performance. We can conclude that the system availability is improved when n_d has a lower value than that for the interferers. The main focus of this study is to establish the optimum PC command rate and step size.

The simulation results show that SINR-based PC with PC/snapshot of 100 (i.e. 6.67 PC/3-dB fading bandwidth) and PC step of 0.5 dB gives the best system availability. However, if the PC/snapshot ratio is decreased to 50 we can achieve almost the same system availability but with a step size of 2 dB. The dynamic range for PC gives the transmitter the chance to compensate for multipath fading; we show that an upper bound on the transmitted power should be imposed.

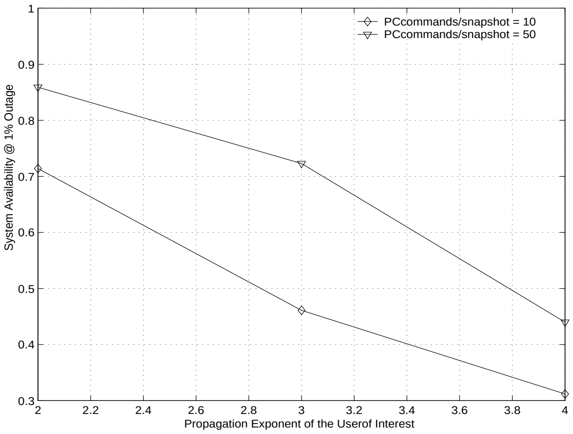

Fig. 3: System availability versus propagation exponent of desired subscriber (n_d). n_i=4, PC/snapshot=10, PC step Δ = 2 dB, α = 0.9, K_i =4 and K_d =10.

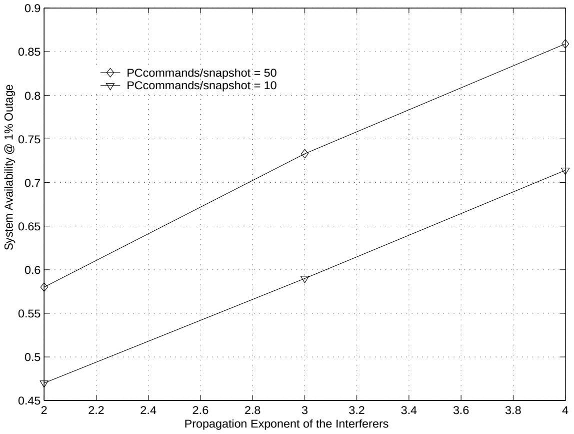

Fig. 4: System availability versus propagation exponent of interferers subscriber (n_i), n_d =2, Δ = 2 dB, and α = 0.9, K_i =4 and K_d =10.

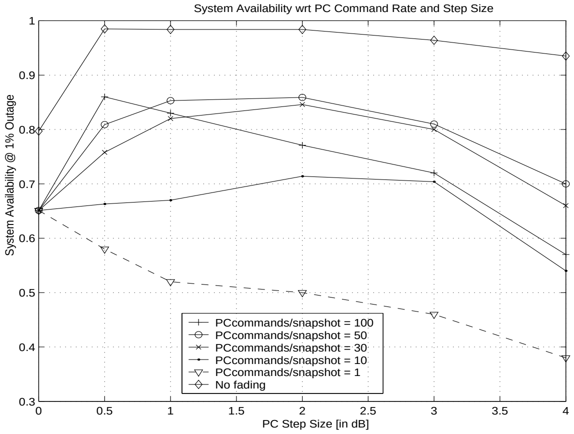

Fig. 5: The effect of power command rate and step size on system availability, with n_d =2, ni= 4, α =0.9, K_i =4 and K_d =10.

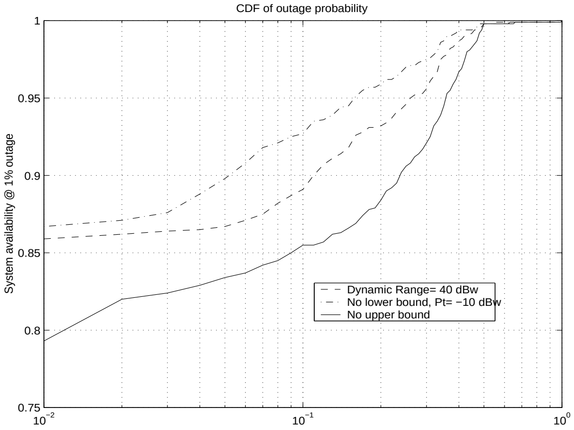

Fig. 6: Effect of transmit power dynamic range on system availability, PC/snapshot = 50, Δ =2 dB, K_i =4 and K_d =10.

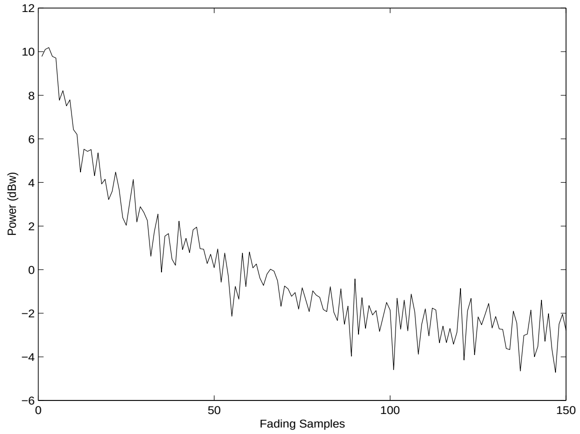

Fig 7: Power spectral density for the fading channel

REFERENCES:

[1] G. Stamatelos and D. D. Falconer, "Millimeter wave radio access to multimedia services via LMDS", *Proc. IEEE Globecom'96*, London, Nov. 1996.

[2] http:// www.ieee802.org/16.

[3] Salem Salamah, "Transmit power control in fixed broadband wireless systems", M.Eng. thesis, Carleton University Aug. 2000.

[4] T.S. Rappaport, Wireless Communications, Principles and Practice, Prentice Hall, 1996.

[5] S. Ariyavisitakul, "SIR-based power control in a CDMA System", *IEEE GLOBECOM*, , vol.II, pp. 868-873, Orlando, Dec. 1992.

[6] S. Ariyavisitakul and L. F.Chang, "Signal and interference statistics of a CDMA system with feedback power control," *IEEE Trans. Commun.*, pp. 1626-1634, Nov. 1993.

[7] S. Gong,D. D. Falconer, "Cochannel interference in cellular fixed broadband access system with directional antennas", *Wireless Personal Communications*, vol. 10, no.1, pp.103-117, 1999, Kluwer Academic Publishers.

[8] N. Naz and D. D. Falconer, "Temporal variation characterization for fixed wireless at 29.5 GHz ," *IEEE VTC 2000*, Tokyo, May 2000