New algorithms for NLOS Identification

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Abstract— **A major concern of cellular and PCS-based wireless location systems is the effect of the harsh propagation environment, particularly non-line-of-sight (NLOS) propagation. In order to improve location accuracy under such conditions, many NLOS mitigation algorithms utilize the knowledge of wether the base station (BS)- mobile station (MS) path is line-of-sight (LOS) or non-line-of-sight (NLOS). In this paper we present four algorithms that utilize the received power envelope characteristics to to perform the NLOS identification.**

I. INTRODUCTION

A potential boon for wireless location technology has been on tap since 1996 when the Federal Communication Commission (FCC) mandated that 911 emergency calls from cellular PCS and phones be traced as those from landline phones. The purpose is to send emergency help to the right location as quickly as possible.

One of the primary issues that inhibits accurate location is the problem of NLOS error. Due to the lack of a LOS path between the MS and a BS, the measured signal path length (or equivalently, TOA) is generally much larger than the true or LOS path due to reflection and/or diffraction in the channel. Consequently, the measured TOAs contain a large positive error, in addition to standard measurement error [1].

For some NLOS mitigation algorithms, it is useful to identify whether a BS is LOS with the MS or not [2]. If we can identify at least three BSs as LOS we can determine the MS location using time-based techniques without the need to mitigate the NLOS error. For the range scaling algorithm (RSA) mentioned in [3], the true range is estimated by constrained minimization. If there is prior information that a BS is LOS, then it becomes necessary to only estimate a reduced number of variables and which will increase the location accuracy. The authors in [2, 4] addressed some NLOS identification methods. In [2], statistical tests on TOA measurements of a stationary MS is used to distinguish between LOS and NLOS MS-BS path. If the statistical tests indicate that the TOA measurements have a Gaussian distribution, then the error in the TOAs is due to the measurement error (i.e. the MS-BS path is LOS), and otherwise it would be a NLOS path. Another way to perform identification is proposed in [4]. The identification is made for five cases that differ in the a priori knowledge of the NLOS pdf, and NLOS error is considered either deterministic or random.

In this paper, we present new algorithms to identify whether a BS is a LOS or NLOS with the MS. The first three algorithms use the power envelope of the received signal for a moving MS to perform the identification, whereas the fourth algorithm utilizes the received power and the TOA measurement to perform the identification. From [5], in the LOS propagation case, the power envelope has a Ricean distribution, whereas in the NLOS propagation case, it has a Rayleigh distribution. Since the Rayleigh distribution is a special case of the Ricean distribution, then by taking some samples of the power envelope and comparing its statistics with the statistics of the Rayleigh fading distribution, we can determine whether the channel is LOS or not.

Thus, for the first algorithm we apply statistical tests, such as the Kolmogorov-Smirnov test, to identify whether the MS-BS path is a LOS or NLOS. We will use the Jakes model to simulate the propagation channel. The second and third algorithms utilize two properties of the envelope, level crossing rate and average fade duration, to compare the envelope statistics [6]. For the NLOS case (Rayleigh distributed power envelope), the level crossing rate is higher than that for the LOS case (Ricean distributed power envelope). Also, the average fade duration tends to be larger for the LOS case than that for the NLOS case.

For the Fourth algorithm, we use the fact that if the measured TOA is for a LOS/NLOS BS, then the received power should obey the LOS/NLOS propagation channel model. So if we compute the received power from the channel model for LOS/NLOS case (after substituting the measured range for the distance in the equation), then we can compare the calculated power with the measured power to see wether it is closer to the LOS model assumption or to the NLOS model assumption, thus we can determine wether the BS-MS path is LOS or NLOS.

In the following, Section II presents the first algorithm which use the pdf of the received power envelope to perform the identification. Section III presents the second and third algorithms which uses the characteristics of the received power envelope to identify wether the BS is LOS or NLOS. The fourth algorithm, which uses the measured TOA and the measured received power together with propagation channel model, is presented in Section IV. Simulation results are given in Section V followed by concluding remarks in Section VI.

II. NLOS IDENTIFICATION USING THE CUMULATIVE DISTRIBUTION OF POWER ENVELOPES

The received complex lowpass signal is given by

$$r(t) = r_I(t) + r_Q(t)$$

which can be modeled as a complex Gaussian process. In the case of NLOS, $r_I(t)$ and $r_Q(t)$ have zero mean, and the received envelope $z(t) = |r(t)|$ has a Rayleigh distribution [5]

$$p_z(x) = \frac{2x}{\Omega} exp\left(\frac{-x^2}{\Omega}\right).$$

where $\Omega = E[z^2]$. For the LOS case, the random variables $r_I(t)$ and $r_Q(t)$ have a non-zero mean and the complex envelope has a Ricean distribution given by

$$p_z(x) = \frac{2x(K+1)}{\Omega} exp\left(-K - \frac{(K+1)x^2}{\Omega}\right) I_o\left(2x\sqrt{\frac{K(K+1)}{\Omega}}\right)$$

and K is the Rice factor.

The basic idea that we depend on to identify whether a BS is LOS or not is that if there is a LOS path between a BS and MS, the power envelope will have a Ricean distribution, and otherwise it will have a Rayleigh distribution. To compare the statistics of the received power envelope and the Rayleigh distribution, we use statistical tests. One of those tests is the Kolmogorov-Smirnov test which indicates how well an observed distribution fits a theoretically expected one. It corresponds to the χ^2 goodness of fit test, and is sensitive to the departures from the shape of the distribution function. The test is also derived for continuous distributions.

The null hypothesis that the sample originated in a population with known distribution function, $F_O(x)$, is tested against an alternate hypothesis that the population underlaying the sample does not have $F_O(x)$ as its distribution function. One determines the absolute frequency, E, expected under the null hypothesis, forms the cumulative frequencies of these values, namely F_E, and of the observed absolute frequencies O, namely F_O, and then forms the differences $F_O - F_E$ and divides the difference largest in absolute value by the sample size n. The test ratio is [11]

$$\hat{D} = \frac{\max|F_O - F_E|}{n}. \tag{1}$$

The level of significance, α, is a measure of the percentage in which the test is wrong. For the level of significance, $\alpha = 0.05$, the bound on D is given by

$$D = 1.358/\sqrt{n} \tag{2}$$

where n is the number of samples. If $\hat{D} < D$, then the null hypothesis is considered true; otherwise, the alternate hypothesis is considered true.

III. NLOS IDENTIFICATION USING TEMPORAL STATISTICAL CHARACTERISTICS OF POWER ENVELOPES

Two important statistics associated with envelope fading are the level crossing rate (how often the envelope crosses a specified level) and the average fade duration (how long the envelope remains below a specified level).

For a Ricean distribution, the level crossing rate, L_R, of a level R is given by [5]

$$L_R = \sqrt{2\pi(K+1)} f_m \rho e^{-K-(K+1)\rho^2} I_0(2\rho\sqrt{K(K+1)}) \tag{3}$$

where I_0 is the modified bessel function of the first kind, K is the Rice factor, ρ is given by

$$\rho = \frac{R}{R_{\text{RMS}}}$$

where R_{RMS} is the rms envelope level and f_m is the maximum Doppler shift. For Rayleigh distribution ($K = 0$) the above expression simplifies to [5]

$$L_R = \sqrt{2\pi} f_m \rho e^{-\rho^2}. \tag{4}$$

Thus, we see that the level crossing rate is different for the Ricean (LOS) and Rayleigh (NLOS) distributions, and we can use this characteristic to distinguish whether a BS-MS path is LOS or not. This is accomplished by comparing the measured level crossing rate, $\hat{L}_R$, with the computed values from (3) and (4), and determine if it is closer to the computed values from the Rayleigh or Ricean distributions. Thus, we can decide if the power envelope distribution is Ricean (LOS) or Rayleigh (NLOS). To make the decision a threshold is assumed at $K = \theta$, so if $L_R(K = 0) \leq \hat{L}_R \leq L_R(K = \theta)$ then the BS is assumed to be NLOS, otherwise it would be LOS.

A second envelope characteristic, the average fade duration, $\bar{t}$, for Ricean distribution is given by [5]

$$\bar{t} = \frac{1 - Q(\sqrt{2K}, \sqrt{2(K+1)\rho^2})}{\sqrt{2\pi(K+1)} f_m \rho e^{-K-(K+1)\rho^2} I_0(2\rho\sqrt{K(K+1)})} \tag{5}$$

and for the Rayleigh distribution $(K = 0)$ it is given by [5]

$$\bar{t} = \frac{e^{\rho^2} - 1}{\sqrt{2\pi} f_m \rho}, \tag{6}$$

where Q is the Marcum Q function.

Again, we can compare the measured level crossing rate, $\hat{t}$, with the computed values from (5) and (6), and determine which distribution results in a closer fit. Also here, to make the decision a threshold is assumed at $K = \theta$, so if $t(K = 0) \leq \hat{t} \leq t(K = \theta)$ then the BS is assumed to be NLOS, otherwise it would be LOS.

Thus we can decide if the power envelope distribution is Ricean (LOS) or Rayleigh (NLOS).

IV. NLOS IDENTIFICATION USING JOINT TOA/RECEIVED POWER MEASUREMENTS

If the TOA (range) measurement is for a LOS/NLOS BS, then the received power should obey the LOS/NLOS path loss model after substituting the measured range for the distance in the model. Thus, we can determine wether the BS is LOS or not. For the simulations in this paper, the Walfisch-Ikegami model of [12] is assumed. This model is suitable for Urban Microcell Propagation. We also consider Rayleigh/Rice fading for the power envelope for the NLOS/LOS case.

The Walfisch-Ikegami path loss model for the LOS case is given by

$$\begin{aligned} L_{LOS} &= L_o + 10\gamma \log(d) \\ L_o &= 42.6 + 20\log(f) \\ \gamma &= 2.6, \end{aligned}$$

where d is the distance between the MS and the BS, f is the signal frequency.

For the NLOS case, the Walfisch-Ikegami path loss model is given by

$$\begin{aligned} L_{LOS} &= L_o + 10\gamma \log(d) \\ L_o &= 32.4 + (30 + k_f)\log(f) - 16.9 - 10\log(w) \\ &\quad +20\log(\triangle h_m) + L_p + k_o + k_a - 9log(w) \\ \gamma &= (20 + k_d)/10 \\ k_o &= -18\log(1 + \triangle h_b) \\ k_a &= 54 - 0.8(\triangle h_b) \\ k_d &= 18 - 15(\triangle h_b / h_{roof}) \\ k_f &= -4 + 1.5[(f/925) - 1], \end{aligned}$$

where h_m is the MS antenna height, h_b is the BS antenna height, h_{roof} is the building height, $\triangle h_b = h_{roof} - h_b$, $\triangle h_m = h_{roof} - h_m$, w is the distance between the street MS and the building and L_p is the loss due to elevation angle.

The identification is performed first by computing two hypothetical values for the received power $E[z^2]$ (assuming that the transmitted power is known priori), the first is $p_{r,LOS} = p_t - L_{LOS}$, and the second is $p_{r,NLOS} = p_t - L_{NLOS}$, where p_t is the transmitted power. The next step is to compute the $\hat{\mu} = E[z]$ and $\hat{\zeta} = E[z^2]$ from the measurement z, then from [5] we see that

$$\mu = E[z] = \sqrt{\Omega}\exp(-K)\frac{\sqrt{pi}}{2} F_1(3/2, 1, K) \tag{7}$$

and

$$\zeta = E[z^2] = \Omega(K + 1) \tag{8}$$

where $F_1(a, b, c)$ is the confluent hypergeometric function. Thus we have two equations (7) and (8) with two unknowns (K, Ω), and we can get the values for the unknowns by minimizing the following equation

$$(K, \Omega) = \arg\min_{K,\Omega} |\hat{\mu} - \mu|^2 + |\hat{\zeta} - \zeta|.$$

The final step in the identification is to see wether Ω is closer to $p_{r,LOS}$ (which implies that the BS is LOS), or to $p_{r,NLOS}$ (which implies that the BS is NLOS).

V. SIMULATIONS RESULTS

Simulations for the all the algorithms were performed to test their performance. In Fig 1, we present the percentage of the BSs that are identified as NLOS BSs for different Rice factors (i.e., for each Rice factor we run 100 cases of MS-BS path and see whether it is a LOS or NLOS). For $K = 0$, we expect to get 100 percent NLOS BSs, and the number of NLOS BSs should decrease as K increases. For the simulations, the carrier frequency is 900 MHz and the sampling frequency is 1000 Hz. The ranges (TOAs) were derived from a DOS scattering model with a radius of 0.5km. The BS location is $(0, 0)$ with all units in km. The MS location is $(x_{\mathrm{ms}}, y_{ms})$ where $x_{ms} = 4.33 \cdot (u + 0.5)$ in km, $y_{ms} = 0.5 \cdot (7.5 + u)$ in km and u is a random variable uniformly distributed in

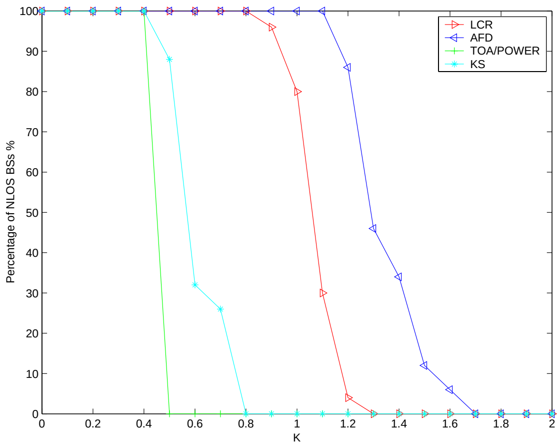

Fig. 1. Percentage of NLOS BSs detected vs the Rice factor (K) using average fade duration (AFD), levelcrossing rate (LCR), Kolmogorov-Smirnov test (KS) and the joint TOA/power-envelope algorithm.

the region $[0, 1]$. The range measurement noise is white Gaussian noise with variance 0.007^2 km^2. The parameter α is chosen to be 0.05 for our simulations. For the LOS case a TOA measurement which corresponds to the direct path between the MS and the BS is assumed for $K > 0.4$, and for the simulations the threshold, θ, is assumed to be equal 1. For the joint TOA/power algorithm, $h_b = 40$m, $h_{roof} = 35$m, $L_p = 0$ and $w = 20$m.

For Fig. 1, the Doppler frequency is set to 100 Hz and the simulated interval is 1 s. The results in Figure 1 show that as the Rice factor increases, we can detect that the BS is LOS, and as the Rice factor approaches 0, the BS is detected as NLOS. The results also show that average fade duration algorithm needs higher values of K to detect a LOS BS, whereas the joint TOA/power algorithm needs less K to detect a LOS BS.

The results in Figs. 2 shows the algorithms performance as we change Doppler frequency for $K = 0.2$. From Fig. 2 we see that all the algorithms could detect the BS as NLOS for all Doppler frequencies except for the Kolmogorov-Smirnov test, which did the detection for maximum Doppler frequency greater than or equal to 40 Hz. As for $K = 3$, the algorithms detected the LOS BS for all maximum Doppler frequencies (the results for this case are not shown in a figure).

The results in Figs.3 shows the algorithms performance as we change the time window over which the samples are taken for $K = 0.2$. From Fig.3 we see that all the algorithms could detect the BS as NLOS for all time windows except for the level crossing rate algorithm, which did the detection for time window greater than or equal to 0.8 seconds. As for $K = 3$, the algorithms detected the LOS BS for all time windows (the results for this case are not shown in a figure).

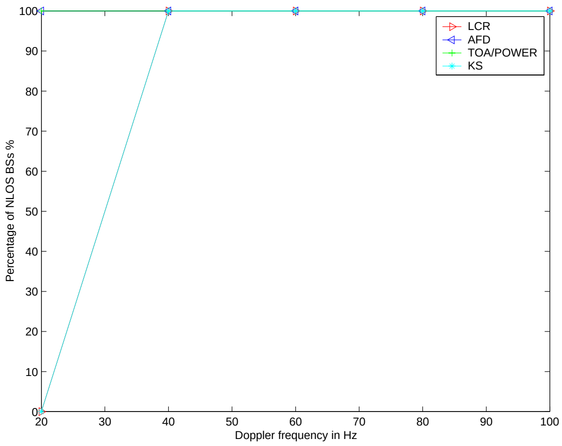

Fig. 2. Percentage of NLOS BSs detected vs Doppler frequency in Hz using average fade duration (AFD), levelcrossing rate (LCR), Kolmogorov-Smirnov test (KS) and the joint TOA/power-envelope algorithm for K=0.2.

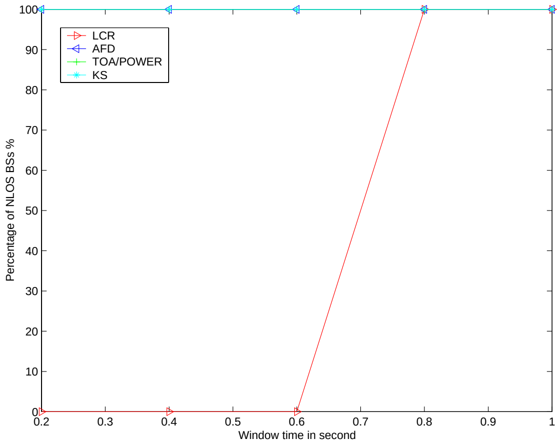

Fig. 3. Percentage of NLOS BSs detected vs time window length in seconds using average fade duration (AFD), levelcrossing rate (LCR), Kolmogorov-Smirnov test (KS) and the joint TOA/power-envelope algorithm for K=0.2.

VI. CONCLUSION

In this paper we presented new techniques to identify whether a MS is in LOS with the BS or not. Identifying a BS is LOS is useful in some NLOS mitigation algorithms. The first algorithm performs the identification by utilizing the statistics of the power envelope of the received signal. The second and third algorithms utilize the characteristics of the power envelope of the received signal to perform the identification. Finally, the fourth and last algorithm uses the TOA and received power information to identify whether a BS is LOS or not. Computer simulations were performed to assess the algorithms performances.

REFERENCES

[1] J. Caffery and G. Stuber, “Subscriber locations in CDMA cellular networks,” *IEEE Trans. on Vehicular technology*, vol. 47,

pp. 406–416, May 1998.

[2] S. Venkatraman and J. Caffery, “Statistical approach to non-line-of-sight BS identification,” *Wireless Personal Multimedia Communications, 2002. The 5th International Symposium on*, vol. 1, pp. 296–300, October 2002.

[3] S. Venkatraman, J. Caffery, and H.-R. You, “Locatin using LOS range estimation in NLOS environments,” *IEEE Veh. Techn. Conference - Spring*, pp. 856–860, 2002.

[4] J. Borras, P. Hatrack, and N. Mandayam, “Decision theoretic framework for NLOS identification,” *Vehicular Technology Conference, 1998. VTC 98. 48th IEEE*, vol. 2, pp. 1583 –1587, May 1998.

[5] G. L. Stuber, *Principles of Mobile Communication*. Kluwer Academic Publishers, 1996.

[6] A. Abdi, K. Wills, H. Barger, M.-S. Alouini, and M. Kaveh, “Comparison of the level crossing rate and average fade duration of Rayleigh, Rice and Nakagami fading models with mobile channel data,” *Vehicular Technology Conference, 2000. IEEE VTS-Fall VTC 2000*, pp. 1850 –1857, September 2000.

[7] Y. Li and X. Huang, “The simulation of independent Rayleigh faders,” *IEEE Transactions on Communications*, pp. 1503–1514, September 2002.

[8] C. Xiao, Y. Zheng, and N. Beaulieu, “Second-order statistical properties of the WSS Jakes’ fading channel simulator,” *IEEE Transactions on Communications*, pp. 888–891, June 2002.

[9] C. Xiao and Y. Zheng, “A generalized simulation model for Rayleigh fading channels with accurate second-order statistics,” *VTC2002-Spring*, pp. 170–174, 2002.

[10] M. Pop and N. Beaulieu, “Design of wide-sense stationary sum-of-sinusoids fading channel simulators,” *ICC 2002*, pp. 709–716, 2002.

[11] L. Sachs, *Applied Statistics A Handbook of Techniques*. Springer-Verlag, 1982.

[12] S. Faruque, “Propagation prediction based on environmental classification and fuzzy logic approximation,” *IEEE International Conference on Communications 1996*, vol. 1, pp. 272–276, june 1996.