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ESTIMATING THE SCATTERING DISTRIBURION OF THE RECEIVED SIGNAL IN MICRO-CELLULAR SYSTEMS

Ehsan Zandi, and Ghasem Azemi

Department of Electrical Engineering,
Faculty of Engineering, Razi University
Kermanshah 67149, Iran.
E-mail: g.azemi@razi.ac.ir
Web: www.razi.ac.ir

ABSTRACT

This paper presents a novel approach for estimating the distribution of the incoming waves at the mobile unit antenna, i.e. the scattering distribution, in a typical micro-cellular system. This estimate is vital in designing unbiased estimators for the velocity of mobile units. The proposed estimator deploys the zero-crossing rates of the quadrature components and the instantaneous frequency of the received signal at the mobile unit to estimate the scattering distribution. By means of simulations, it is shown that the proposed estimator exhibits small bias and root mean square error.

1. INTRODUCTION

Multi-path fading in a mobile communication environment is due to the constructive/destructive superposition of many reflected, scattered, and diffracted plane waves arriving at the mobile unit. In a typical micro-cellular environment, the mobile unit is surrounded by local scatterers so the plane waves arrive from different directions. However, in micro-cellular systems the base stations' antennas are only moderately elevated above the scatterers. Therefore, the arriving plane waves arrive in from different directions, with non-equal probability. It follows that in such systems, two-dimensional non-isotropic scattering is a very commonly used scattering model for the forward channel [1].

The estimation of the scattering distribution is of great importance in micro-cellular systems in order to have accurate estimates of the velocity of the mobile units. The estimates of the velocity themselves are necessary for effective handover and dynamic channel assignment in cellular systems and also for designing adaptive power control algorithms for code-division multiple access (CDMA) systems [2],[3]**.** Several methods for estimating the velocity of an mobile station (MS) have been presented in the literature. These include the use of the zero-crossing rate[1] (ZCR) of the in-phase or quadrature components of the received signal as well as the rate of maxima[2], level crossing rate [4], the auto-covariance of the envelope of the received signal [5], and the instantaneous frequency (IF) of the received signal [6]. The IF-based estimator is proven to outperform the other estimators in the presence of shadowing. All the aforementioned velocity estimators are derived with the assumption that the distribution of the scattering component is isotropic. Therefore, those estimators will be significantly biased when being used to estimate the velocity of an MS moving in a micro-cellular environment.

In this paper, using a suitable model for the distribution of the incoming waves at the mobile unit antenna, a new method for estimating the scattering distribution of the received signal in a typical micro-cellular system is presented. The proposed estimator uses the ZCR of the quadrature components and the IF of the received signal to estimate the scattering distribution. The proposed estimator can be used to modify the existing velocity estimators to take into account the distribution of the scattering of the received signal.

The remainder of this paper is organized as follows: Section 2 describes the model and the statistics of the received signal. In Section 3, the proposed estimator for the scattering distribution is derived. The performance of the proposed estimator is evaluated using the computer simulations in Section 4. Finally, Section 5 concludes the paper.

2. CHARACTERISTICS OF THE RECEIVED SIGNAL

In a typical micro-cellular system, the multi-path component of the received signal at the mobile unit is assumed to follow the model given by [3]:

$$x(t) = r(t)\cos(2\pi f_c t + \varphi(t)) \quad (1)$$

Where f_c is the carrier frequency, and $r(t)$ and $\varphi(t)$ are the envelope and phase of the received signal, respectively. In the absence of a line-of-sight component, the envelope of the received signal is known to have Rayleigh distribution. Also, the IF of the received signal is defined as:

$$f_{i,y}(t) = \frac{1}{2\pi}\frac{d\varphi(t)}{dt} \quad (2)$$

[1] The ZCR is defined as the average numbers of positive-going zero crossings per second.

[2] The ROM is defined as the average number of maxima per second.

In order to quantitatively study the effects of the scattering distribution of the received signal, the Von-Mises density is deployed. This p.d.f. is given by [7]:

$$p(\theta) = \frac{1}{2\pi I_0(\chi)} e^{\chi \cos\theta} \qquad ; \chi \geq 0, -\pi \leq \theta \leq \pi \quad (3)$$

where the parameter χ determines the directivity of the incoming waves and θ is the arrival angel of the incoming wave and $I_n(.)$ is the modified Bessel function of the first kind of order n. It can be easily verified that for $\chi = 0$ the scattering distribution is isotropic ($p(\theta) = 1/2\pi$), while for $\chi > 0$ it is non-isotropic and as χ increases, the incoming waves become more directive. This model has proved a suitable tool for studying the effects of the scattering distribution in wireless communications.

Using the given model in (3) for the scattering distribution, it is shown in [6] that the ZCR of the quadrature components of the received signal, N_{ZCR}, is derived as:

$$N_{ZCR} = f_m \sqrt{\frac{I_0(\chi) + I_2(\chi)}{2I_0(\chi)}} \quad (4)$$

where f_m is the maximum Doppler frequency shift. Also, in [8, p.135] Rice gives the ZCR of the IF of the signal $x(t)$ in (1) as : $ZCR_{f_{i,y}} = \frac{1}{2\pi}\sqrt{\frac{a_4}{a_2} - \frac{a_2}{a_0}}$ (5)

where a_n, $n = 0,2,4$ is the n$^{\text{th}}$ spectral moment of $x(t)$. Based on the results in [9] , (5) can be rewritten as:

$$ZCR_{f_{i,y}} = f_m \sqrt{\frac{3I_0(\chi) + 4I_2(\chi) + I_4(\chi)}{4\left(I_0(\chi) + I_2(\chi)\right)} - \frac{I_0(\chi) + I_2(\chi)}{2I_0(\chi)}} \quad (6)$$

The proposed estimator for the scattering distribution parameter χ, is derived from the equations (4) and (6).

3. PROPOSED ESTIMATOR

In this Section, the ZCR of the quadrature components and the IF of the received signal, N_{ZCR} and $ZCR_{f_{i,y}}$, respectively, are used to derive the proposed estimator for the scattering distribution parameter χ.

From (4) and (6) we obtain:

$$\frac{N_{ZCR}}{ZCR_{f_{i,y}}} = \left(\frac{I_0(\chi)\left(3I_0(\chi) + 4I_2(\chi) + I_4(\chi)\right)}{2\left(I_0(\chi) + I_2(\chi)\right)^2} \right)^{-\frac{1}{2}} \triangleq R(\chi) \quad (7)$$

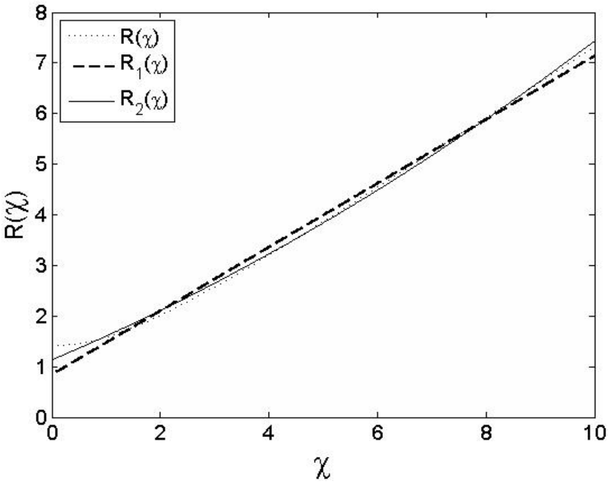

Figure 1- $R(\chi)$ in (7) versus χ. We observe that $R(\chi)$ can be well-approximated by a low-order polynomial.

Using (7), an estimate for the parameter χ can be achieved by first estimating the ZCRs, N_{ZCR}, and $ZCR_{f_{i,y}}$. However, (7) does not provide a closed form estimator for χ. Rather, χ can be obtained using a Lookup table.

To overcome this shortcoming, we approximate the function $R(\chi)$ in (7) and derive closed form estimators. Figure 1 plots $R(\chi)$ for $\chi \in [0,10]$. It suggests that $R(\chi)$ can be well-approximated with low-order polynomial functions $R_N(\chi) = \sum_{i=0}^{N} p_{iN}\chi^i$. The coefficients $p_{iN}; i = 0,1,...,N$ are computed by fitting $R_N(\chi)$ to $R(\chi)$ in a least-squares sense.

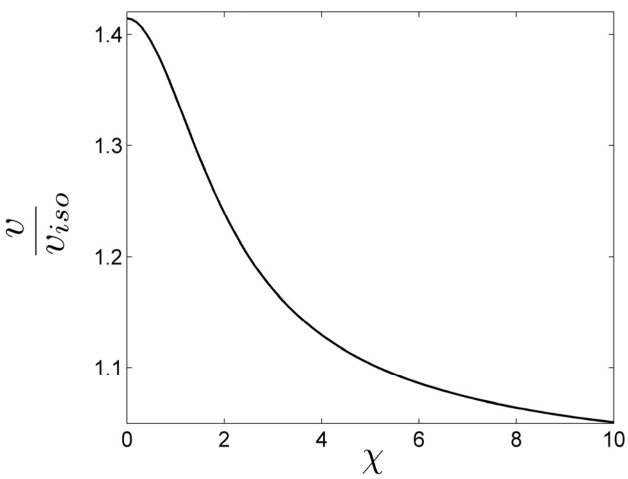

Figure 2- The effect of the non-isotropic scattering on the velocity estimation.

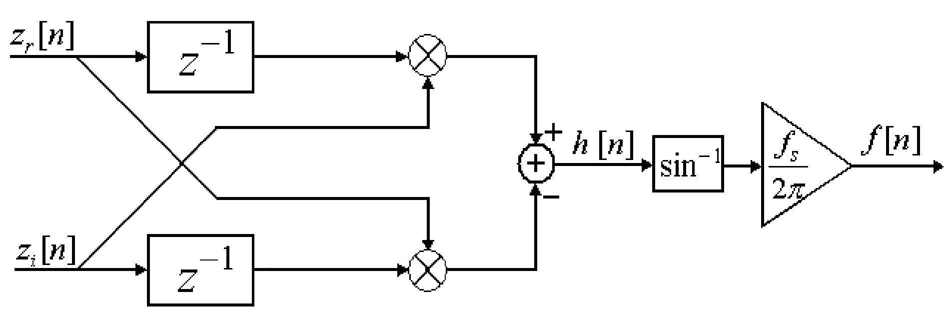

Figure 3- Block diagram of the IF estimator used in our simulation.

Following this approach, $R(\chi)$ is approximated by first and second order polynomials ($N = 1,2$) and the coefficients are calculated as:

$$p_{01} = 0.8365, \qquad p_{11} = 0.62967 \qquad (8)$$

$$p_{02} = 1.1329, \quad p_{12} = 0.45167, \quad p_{22} = 0.017801. \quad (9)$$

Figure 1 also shows the approximates $R_1(\chi)$ and $R_2(\chi)$. After solving the equations $R_N(\chi) = \frac{N_{ZCR}}{ZCR_{f_{i,y}}}; N = 1, 2$ the first order and second order estimates of χ (i.e. $\hat{\chi}_1$ and $\hat{\chi}_2$) are derived as:

$$\hat{\chi}_1 = \frac{E - p_{01}}{p_{11}} \qquad (10)$$

$$\hat{\chi}_2 = \frac{-p_{12} + \sqrt{p_{12}^2 - 4p_{22}(p_{02} - E)}}{2p_{22}} \qquad (11)$$

where E is the ratio of the estimated ZCRs of the quadrature components and the IF of the received signal ($\frac{N_{ZCR}}{ZCR_{f_{i,y}}}$).

In order to illustrate the importance of an accurate estimate of χ in estimating the velocity of a mobile unit, for a typical velocity of $v = 50\ Km/h$, the ratio of v/v_{iso} is plotted in Figure 2 against different values of χ. The velocity v_{iso} is the estimated velocity using a typical ZCR-based velocity estimator assuming isotropic scattering, i.e. $\chi = 0$. It is observed that for $\chi < 5$, not knowing the value of the directivity parameter, leads to a bias of almost 25% in estimating a given velocity. It is worth mentioning that the ZCR-based velocity estimator is more robust to the scattering distribution than the other estimators [4].

4. SIMULATION RESULTS

In this Section, computer simulation is used to evaluate the performance of the proposed estimators when only a finite duration of the received signal is observed.

The complex low-pass equivalent of the received signal, $y[n] = r[n]e^{j\varphi[n]}$, was modeled using the modified Clarke's simulator presented in [9]. This simulator deploys two statistically independent low-pass filtered white Gaussian processes to generate samples of the in-phase and quadrature components of the received signal. The coefficients of the filters were determined based on the power spectral density of the quadrature components of the multi-path signal. The sampling frequency, f_s and the maximum Doppler frequency shift, f_m, were chosen to be 0.5 KHz and 50 Hz, respectively. For each value of χ, a window of one second of the simulated signal was used to estimate the scattering distribution parameter.

The IF of the simulated signal was computed using the real base-band delay demodulator given in [10]. In this approach the simulated signal $y[n]$ is first normalized:

$$z[n] = \frac{y[n]}{|y[n]|} = z_r[n] + jz_i[n] \qquad (12)$$

and the IF is then computed using the block diagram shown in Figure 3. It can be easily verified that $h[n]$ is given by:

$$\begin{aligned} h[n] &= \sin(\varphi[n])\cos(\varphi[n-1]) - \sin(\varphi[n-1])\cos(\varphi[n]) \\ &= \sin(\varphi[n] - \varphi[n-1])] \end{aligned} \qquad (13)$$

It follows that the output of the block diagram, $f[n]$, is derived as:

$$f[n] = f_s \frac{\varphi[n] - \varphi[n-1]}{2\pi}. \qquad (14)$$

Therefore, $f[n]$ is an estimate of the IF of $z[n]$ which is equal to the IF of $y[n]$.

The ZCRs were then used to estimate the scattering distribution parameter, χ, using (10) and (11).

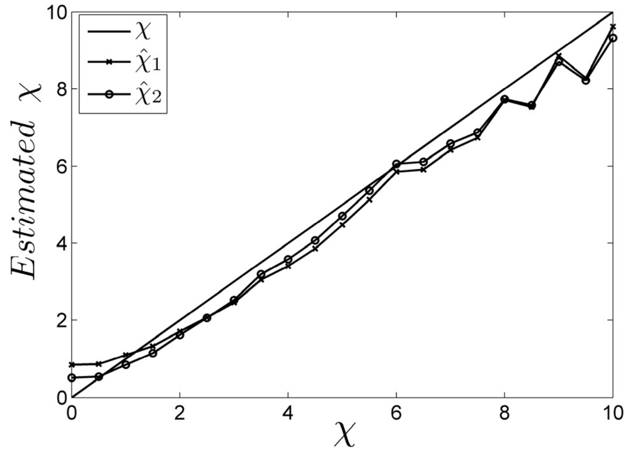

Figure 4- Estimated values of χ using the proposed estimators in (10) and (11)

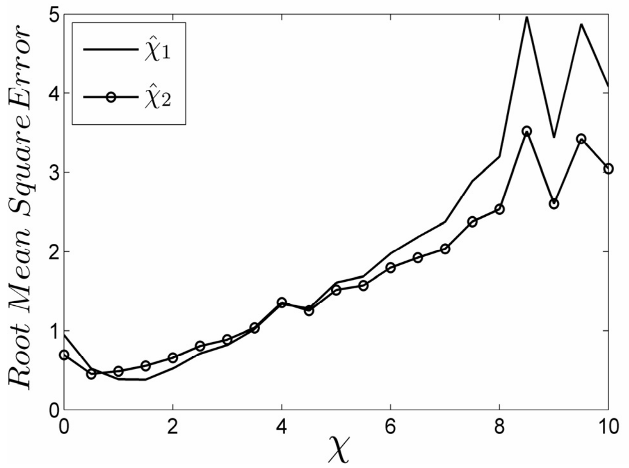

Figure 5- The RMSE of the proposed estimators.

Figure 4 shows the estimated values for the two above mentioned estimators against different values of χ, over 100 realizations of the received signal.

The root mean square error (RMSE) of the estimators is also plotted in Figure 5. We observe that the bias and the RMSE of the proposed estimators are small.

5. CONCLUSIONS

Two new closed form estimators for the scattering distribution in a micro-cellular system with non-isotropic scattering were proposed. The estimators were based on the ZCR of the quadrature components and the IF of the received signal. It was shown that the bias and the RMSE of the proposed estimators are quite small. The proposed Estimators can be used to modify the existing estimators for the velocity of a mobile unit in micro-cellular systems.

6. ACKNOWLEDGEMENT

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REFERENCES

[1] G. L. Stüber, *"Principles of mobile communication*s", 2th ed. Boston, MA: Kluwer Academic Publishers, 2002.

[2] A. Abdi and M. Kaveh, "A new velocity estimator for cellular systems based on higher order crossings," *In the Proc. of the Asilomar Conference on Signals, Systems, and Computers*, vol. 2, pp. 1423-1427, Nov. 1998.

[3] H. Lee and D. Cho, "A new adaptive power control scheme based on mobile velocity in wireless mobile communication systems," *In the Proc. of the Vehicular Technology Conference, IEEE 53rd*, vol. 4, pp. 2878-2882, 2001.

[4] M. D. Austin and G. L. Stüber, "Velocity adaptive handoff algorithms for microcellular systems," *IEEE Trans. Veh. Technol.*, vol. 43, pp. 549-561, Aug. 1994.

[5] K. D. Anim-Appiah, "On generalized covariance-based velocity estimation," *IEEE Trans. Veh. Technol.*, vol. 48, pp. 1546-1557, Sep. 1999.

[6] G. Azemi, B. Senadji, and B. Boashash, "Mobile unit velocity estimation in micro-cells based on the instantaneous frequency of the received signal," *IEEE Trans. Veh. Technol.*, vol. 53, pp. 716-724, May 2004.

[7] C. Tepedelenlioglu and G. B. Giannakis, "On velocity estimation and correlation properties of narrow-band mobile communication channels," *IEEE Trans. Veh. Technol.*, vol. 50, pp. 1039-1052 Jul. 2001.

[8] S. O. Rice, "Statistical properties of a sine wave plus random noise," *Bell Syst. Tech. J.*, vol. 27, pp. 109-157, 1948.

[9] G. Azemi, E. Zandi, and L. Mohammadi, "Simulation of multipath fading channels with non-isotropic scattering " *In the Proc. of the International Conference on Signal Processing and Communication Systems (ICSPCS*), pp. 633-637, Dec. 2007.

[10] Y. Fubing, "FPGA implementation of fully digital FM demodulator," *In the Proc. of the Ninth International Conference on Communication Systems, (ICCS'04)* , pp. 446-450, 2004.