Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 827904, 4 pages
http://dx.doi.org/10.1155/2013/827904

Research Article

Improving the Body Area Line-of-Sight Density Model: A Theoretical Study

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Received 7 February 2013; Revised 20 March 2013; Accepted 20 March 2013

Academic Editor: Duixian Liu

The statistical model plays an important role in BAN radio propagation characterization. However, a traditional least-square statistical model is not necessarily the best choice when only limited samples can be collected. This paper proposes the method for improving the density model in BAN radio propagation characterization; the final PDF result validates the correctness of the method.

1. Introduction

In radio propagation characterization, propagation models have been developed as a suitable alterative solution to measurement campaigns [1]. Statistical models, as an essential kind of propagation model, have been broadly applied to various environments [2–8]. Recently, statistical propagation models for Body Area Networks (BANs) attract more and more attention: in [9], the authors presented a dynamic on-body channel model based on a time-variant measurement campaign at 2.45 GHz in the 3–5 GHz band; Fort et al. [10] measured electromagnetic waves near the torso and derived relevant statistics; in [11], Kim and Takada presented the characterization of an on-body propagation channel with a specific activity of a body on the basis of the measurement results of a male subject in a radio anechoic chamber. From all these examples, we learned that statistical models have become an indispensable part in BAN channel characterization. The statistical model, essentially, is a set of probability distributions in the sample space [12], when it is applied to channel characterization for BANs; so the specific applications are large-scale fading models and probability models of the two, the latter containing time domain characterization as well. In this paper, we mainly focus on the improvement of density models for BANs, since the results and idea are of certain reference value for the BAN channel characterization method.

2. Density Estimation with Regression Method

From [13, 14], we know that the density estimation $p(t)$ is the solution of the equation

$$\int_{-\infty}^{\infty} \theta(x-t)\, p(t)\, dt = F(x), \tag{1}$$

where $\theta(k)$ is a step function, and $F(x)$ is the probability distribution function. Meanwhile, the following conditions will be met:

$$P(x) \geq 0, \qquad \int_{-\infty}^{\infty} p(x)\, dx = 1. \tag{2}$$

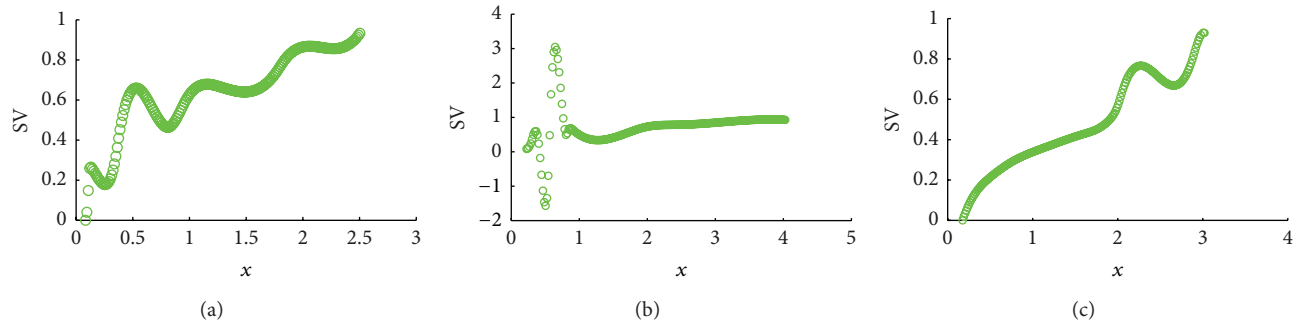

Figure 1: SV for RMS delay.

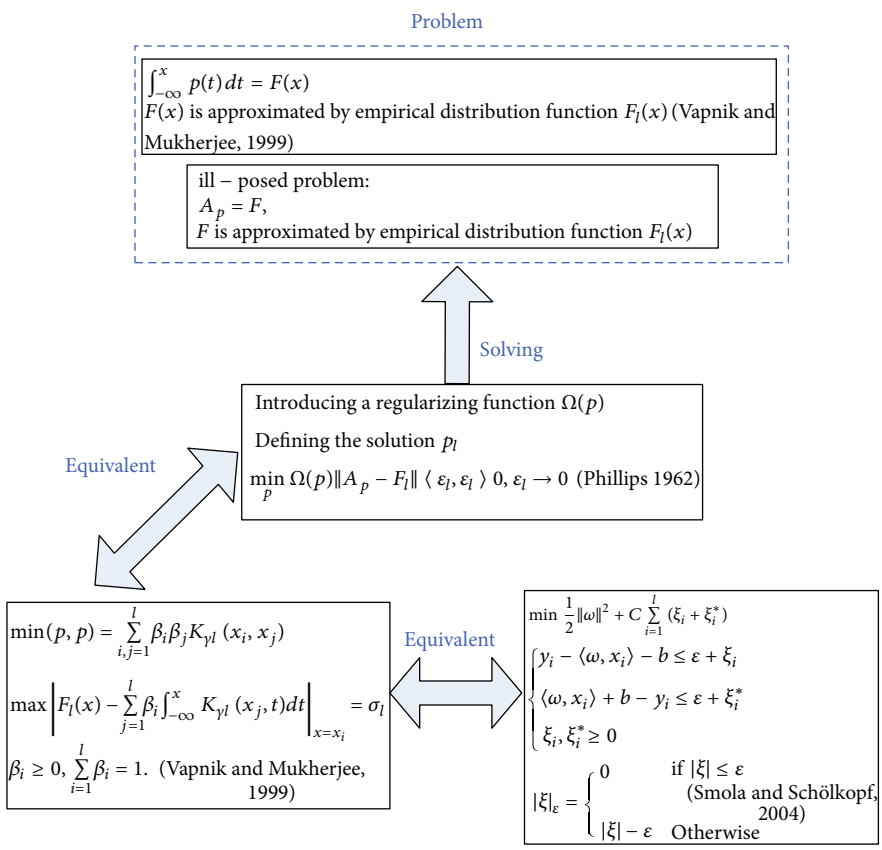

Figure 2: The algorithm for density estimation in BANs.

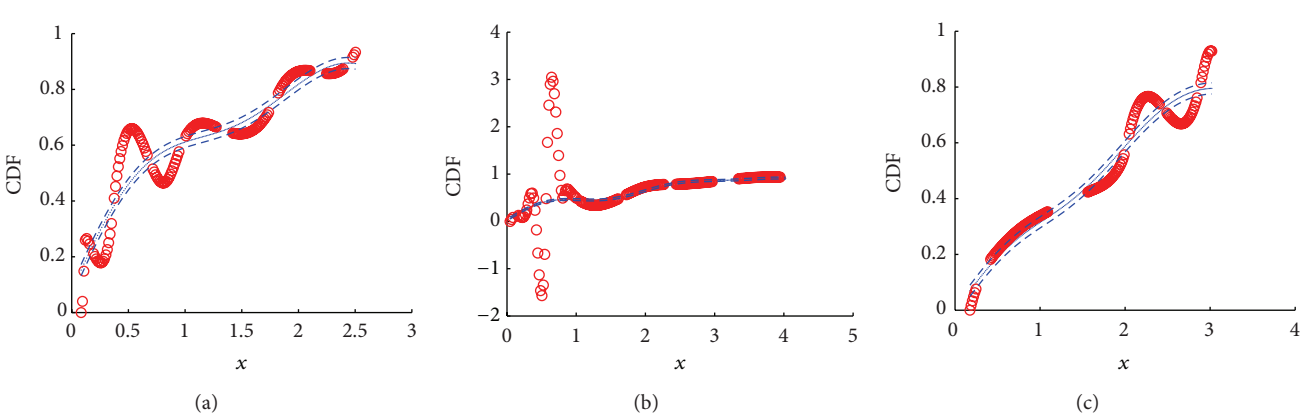

Figure 3: ε-insensitive method.

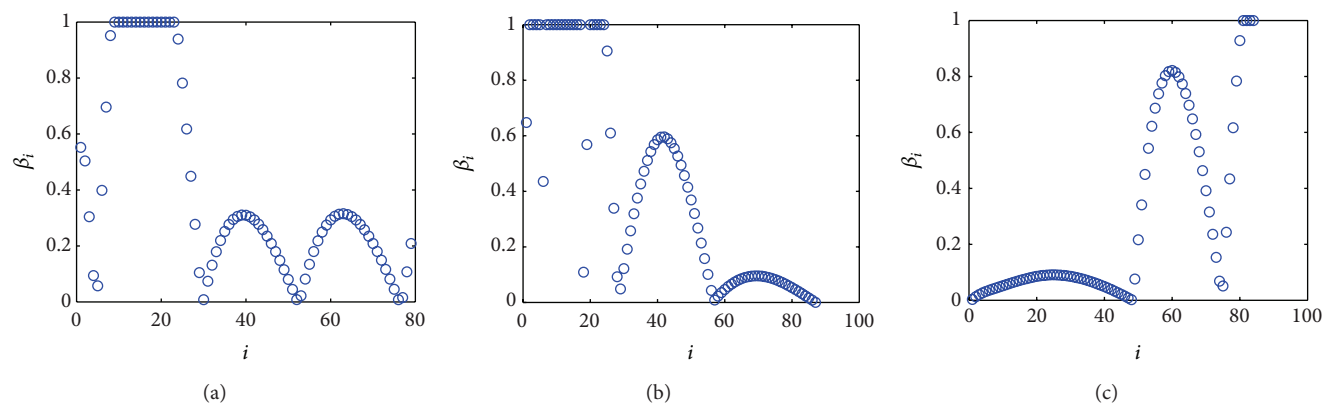

Figure 4: Regression coefficient.

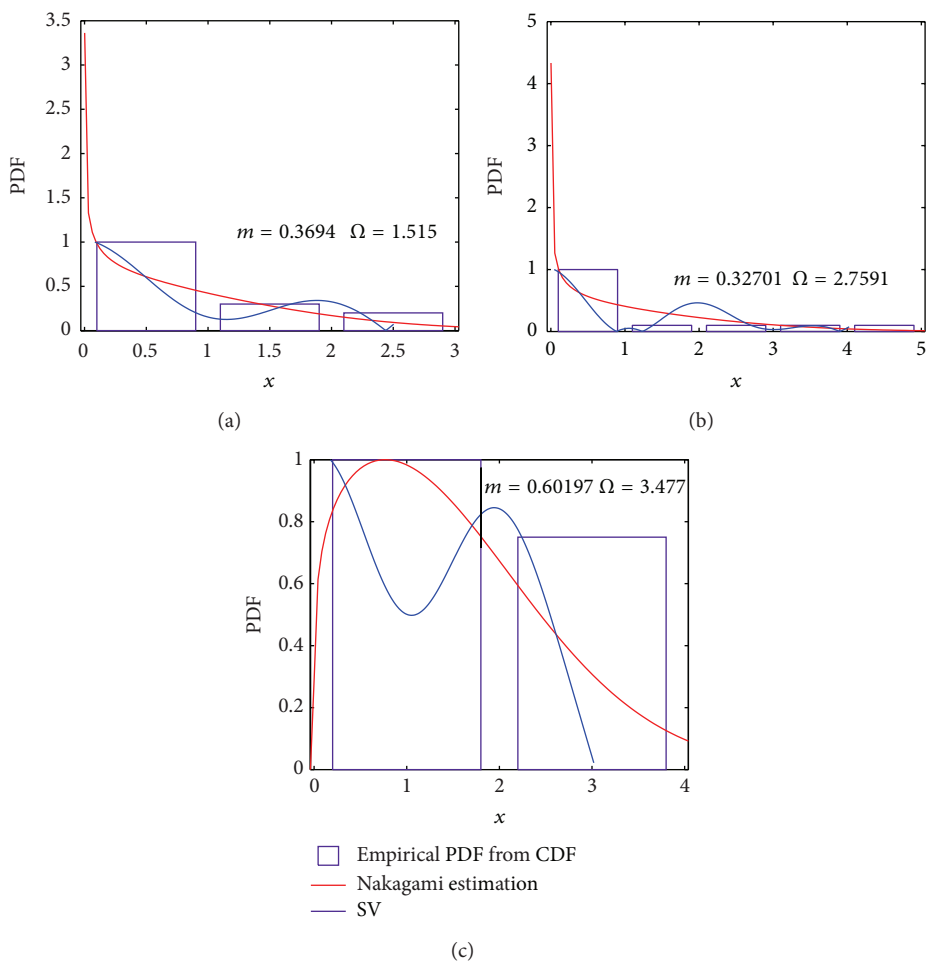

Figure 5: Density estimation comparisons for the RMS delay spread.

It is worth noting that, in (1), the distribution function $F(x)$ is unknown, but a random i.i.d. sample $x_1, \ldots, x_l$ is given; then the empirical distribution function is given [15]:

$$F_l(x) = \frac{1}{l}\sum_{i=1}^{l}\theta(x - x_i), \tag{3}$$

where $\theta(u)$ is a step function. We cite a common time domain parameter (root mean square delay spread) for characterizing BAN channels as an example to build the empirical distribution function. The sampling points cover the chest, the arms, and the legs (the data were measured at the Body-Centric Lab, Queen Mary, University of London); the empirical distribution function can be seen as an approximation of actual probability density function.

The method and the train of thought for density estimation are shown in Figure 2.

After establishing the empirical distribution function, we used the ε-insensitive method [16] to approximate $F_l(x)$. In Figure 3, the cumulative distribution function for the SV regression is shown where the SV is only shown in Figure 1. The ε-insensitive loss function $|\xi|_\varepsilon$ is described by [17]

$$|\xi|_\varepsilon = \begin{cases} 0 & \text{if } |\xi \leq \varepsilon| \\ |\xi| - \varepsilon & \text{otherwise.} \end{cases} \quad (4)$$

In our case, the spacing between the dotted lines is 2ε.

We do care about the coefficient (Figure 4) in the regression process; these coefficients β_i are just the ones which would be used to do the final probability density function regression.

Figure 5 presents the density estimation results, while reasonable approximation demonstrates the feasibility and potentiality of this method. In addition, Figure 5 exhibits the traditional method as well: Nakagami distribution is very common in characterizing on-body RMS delay [18], and the results show that this density distribution is not necessarily the best choice.

3. Conclusion

Statistical model is an important mean of characterizing radio propagation in the BAN propagation environment and other propagation environments. In this paper, the authors try to improve the density estimation method for limited samples in an on-body line-of-sight scenario. In traditional BAN probability density models, least square technique is used to do the regression analysis; however, when the sample size is small, the precision of this method is debatable. In this paper, we proposed new mathematical mechanism to approximate probability density, the final result demonstrates the correctness of the proposed method, and this newly proposed model has extensive reference meaning for statistical radio propagation modeling.

Acknowledgments

The authors would like to thank Dr. Akram Alomainy and Professor Yang Hao, Queen Mary, University of London, UK, for comprehensive guidance; Dr Xueli Chen, Dr. Karen M. von Deneen, Professor Jimin Liang, and Professor Jie Tian, Xidian University for valuable suggestions. This work was supported by the National Natural Science Foundation of China (Grant no. 61250110542) and the Fundamental Research Funds for the Central Universities (no. K5051310004).

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