2001年度 第14回 信號處理合同學術大會 論文集 第14卷 1號

웨이블릿을 이용한 속도 측정

이창수*, 송훈근**, 유경렬*
* 한양대학교 전기공학과, ** LG전자 차세대통신연구소

Speed Estimation of a Mobile Station Using the Undecimated Discrete Wavelet Transform

Chang Soo Lee*, Hun Guen Song**, and Kyung Yul Yoo*
* Department of Electrical Engineering, Hanyang University
** Advanced Telecom. Research Laboratory, LG Eletronics
breatheonme@hanmail.net, hgsong@lge.com, and yoo@emc.hanyang.ac.kr

Abstract

This paper introduces a new technique for estimating the speed of a mobile station in a wireless system. The proposed method is based on the feature extraction of the received signal envelope. The undecimated discrete wavelet transform via lifting captures local minimum points of the received signal, which is used for the speed estimation. This technique requires neither knowledge of the average received power of the nonstationary signal nor adaptation of a temporal observation window, in contrast to other speed estimators given in the literature. Simulations show that the proposed speed estimator tracks the variable speed of the mobile station.

1. Introduction

Next generation wireless cellular systems such as Universal Mobile Telecommunication Systems (UMTS) will allow communications with a mobile station speed up to 500km/h. The time-varing nature of the propagation channel would induce a considerable multipath fading, which could lead to performance degradations of different functions of the transmission chain [1].

The knowledge of this multipath fading effect can help to optimize the mobile transmission system at the physical level as well as at the higher levels of the protocol stack. For example, the interleaving lengths may be optimized to reduce the reception delay based on this information. The related speed estimation can also greatly influence the cell layer assignment strategy: low speed mobile stations would be assigned to pico-cells, medium speed mobile stations to micro-cells, and high speed mobile stations to macro-cells. The location services that rely on the emission of control information at a rate proportional to the mobile velocity also require a speed estimation [1].

Estimation of the mobile velocity can be obtained by using the statistics of the received signal. For example, level crossing rates or the autocovariance of the received envelope have been used to estimate speed. Speed estimates have also been obtained by estimating the maximum Doppler frequency using eigenspace methods, spectrum estimation methods, and the squared deviations of the logarithmically compressed envelope. Another method of velocity estimation requires knowledge of the average signal strength for all locations within a region of interest and uses a technique similar to the multidimensional scaling method of statistical data analysis. All of the above techniques require estimates of the signal power, and some methods also require the signal autocorrelation. A difficulty in obtaining such estimates is the nonstationary nature of the received signal. An appropriate window which depends on the unknown mobile speed must be chosen to estimate the required quantities. Furthermore, the above-mentioned literature has considered only the problem of a constant, unknown mobile speed. For variable speeds, the duration of the observation window must be constantly adapted, and the rate of adaptation will be critical to the performance of the speed estimator. In particular, errors in the speed estimators could propagate due to suboptimal observation windows [2].

In [2], the method of speed estimation using the wavelet transform modulus maxima (WTMM) has been described. The wavelet transform at different scales corresponds to a variety of window lengths and, hence, eliminates the requirement of adapting the duration of a single temporal observation window. The method presented utilizes the fact that the small-scale spatial variation of the received envelope is dominated by the positions of the mobile and base stations. This spatial variation has a characteristic scale that is on the order of a carrier wavelength. The temporal variation of the received envelope is then a consequence of mapping the spatial variation through the mobile speed. By tracking the characteristic temporal scale of the variations, an estimate of the speed is obtained as a function of time.

The WTMM representation of a signal records the values and locations of local maxima of its wavelet transform modulus (WTM). Although the WTMM-based algorithms give a promising performance in many aspects, it is based on the continuous wavelet transform (CWT), which means that it is not suitable for practical implementation [3]. In this paper, a speed estimator using the undecimated discrete wavelet transform (UDWT) is proposed for practical implementation.

This paper is organized as follows. Section 2 provides a wireless propagation model. In Section 3, a method for the speed estimation using the UDWT via lifting is presented. Section 4 shows simulation results for a variable speed estimator. Finally conclusions are given in Section 5.

2. Propagation Characteristics of Mobile Radio Channels

In an ideal radio channel, the received signal would consist of only a single direct path signal so that a perfect reconstruction of the transmitted signal is possible. However, in a real channel, the signal is modified during transmission in the channel. The received signal consists of a combination of attenuated, reflected, refracted, and diffracted replicas of the transmitted signal. On top of all this, the channel adds noise to the signal and can cause a shift in the carrier frequency if the transmitter, or receiver is moving (Doppler effect). Understanding of these effects on the signal is important because the performance of a radio system is dependent on the radio channel characteristics [4].

Attenuation is the drop in the signal power when transmitting from on point to another. It can be caused by the transmission path length(path loss), obstructions in the signal path(shadowing), and multipath effects. Any objects which obstruct the line of sight signal from the transmitter to the receiver, can cause attenuation. Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver. It is generally caused by buildings and hills, and is the most important environmental attenuation factor. Shadowed areas tend to be large, resulting in the rate of change of the signal power being slow. For this reason, it is termed slow-fading, or log-normal shadowing [4].

In a radion link, the RF signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles. This gives rise to multiple transmission paths at the receiver. The relative phase of multiple reflected signals can cause constructive of destructive interference at the receiver. This is experienced over very short distances (typically at half wavelength distances), thus is given the term fast fading. These variations can vary from 10-30dB over a short distance. Fig. 1 shows the level of attenuation that can occur due to the fading. The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received signal power. It describes the probability of the signal level being received due to fading [4].

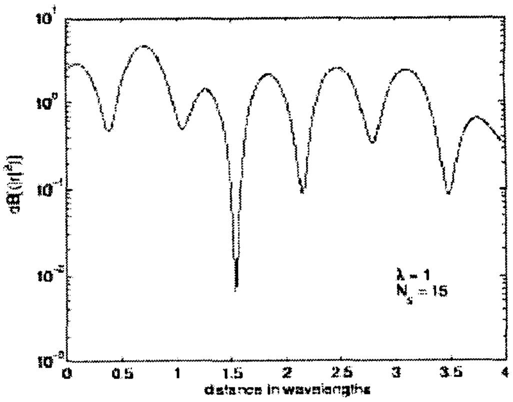

Figure 1. Typical Rayleigh fading

The propagation model considered here consists of three effects: path loss, shadowing, and multipath fading [5]. The path loss describes the tendency of signal power to decrease as an inverse power of distance from the transmitter. Typically, it is taken as inverse fourth power at any distance r, so that

$$P_p = \frac{P_o}{r^4} \qquad (1)$$

where P_o is a proportionality constant and the subscript p denotes path loss. The scale of shadowing variations depends on the size of the obstacles between the base and mobile, but we usually expect it to be roughly constant over a few tens of wavelengths and to exhibit significant variation over hundreds of wavelengths. The received signal power, after accounting for both path loss and shadowing is

$$P_{ps} = \frac{P_o}{r^4} 10^{0.1z} \qquad (2)$$

where z is a Gaussian random variable with zero mean and standard deviation in the range 6 dB to 10 dB, depending on the terrain, and the subscript ps denotes combined path loss and shadowing.

We assume that there are N_s multipath rays around the mobile. If the mobile is translated a distance x, then the received complex envelope $y(t)$ due to the multipath fading is

$$\begin{aligned} y(t) &= \sum_{i=0}^{N_s-1} a_i \exp[j\, 2\pi\, f_D\, t \cos\theta_i]\, s\left(t - \frac{x_i}{c}\right) \\ &= \sum_{i=0}^{N_s-1} a_i \exp[j\, 2\pi\, \frac{vt}{\lambda} \cos\theta_i]\, s\left(t - \frac{x_i}{c}\right) \qquad (3) \\ &= g(t)\, s(t - \tau_i) \end{aligned}$$

where a_i are reflection coefficients and x_i are a path length for individual paths, indexed by i. The received signal $r(t)$, after combining path loss, shadowing, and multipath effects, is then given by

$$r(t)=\sqrt{2P_{ts}}\; g(t)\; s(t-\tau_i) \tag{4}$$

3. Speed Estimation Using the Undecimated Lifting

The speed estimation technique introduced here is based on the time difference of local minimum points which are extracted from the logarithm of the received envelope by using the undecimated discrete wavelet transform. Even if the differences between local minimum points in wavelengths are fixed as approximately half of a wavelength ($\lambda/2$), time differences Δt of local minimum points are dependent on the mobile speed v. Also, the maximum Doppler frequency changes according to the mobile speed. In order to estimate the mobile speed, the received envelope should be represented as time scale t. Then the estimated speed is given as

$$\hat{v}=\frac{k\,\lambda}{\Delta t} \tag{5}$$

where k is approximately 1/2. A method to estimate $\Delta T(t)$ using the undecimated lifting is described in the following [2].

The undecimated discrete wavelet transform (UDWT) differs from the traditional DWT because it does not employ a decimator after filtering. This is also known as the redundant or translation invariant DWT. There are several implementations of the UDWT, such as the stationary and the translation invariant (cycle-spinning) wavelet transforms [6, 7]. The absence of a decimator leads to a redundant signal representation. The translation invariant property of the UDWT makes it preferable for use in various signal processing applications, as it relies heavily on spatial information [8].

The UDWT via lifting is based on a polyphase structure, where the downsampling and split stage are removed. This structure maintains the same performance as other UDWTs, yet it inherits some benefits of the lifting scheme, such as the integer-to-integer transform, parallel implementation, and the design simplicity of the inverse transform [9, 10].

Lifting, a space-domain construction of biorthogonal wavelets, consists of the iteration of the three basic operations; split, predict, and update operations [9].

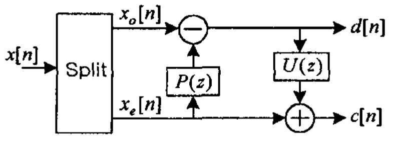

Figure 2. Lifting stage: Split, Predict, Update

To develop an undecimated lifting scheme, the processing of the stationary wavelet transform is converted into lifting steps [11]. First, the DWT is represented in the polyphase form of the lifting scheme and then the decimator and upsampler are removed. We upsample the lifting operators during the progressive stages of processing. The undecimated 4-point predict operator $P_u(z)$ and update operator $U_u(z)$ are

$$P_u(z) = z^{-1}P(z^2) = p_1z^{-3} + p_2z^{-1} + p_3z^1 + p_4z^3 \tag{6}$$
$$U_u(z) = zU(z^2) = u_1z^{-3} + u_2z^{-1} + u_3z^1 + u_4z^3 \tag{7}$$

Fig. 3 shows the iterations of the undecimated lifting which construct the forward UDWT. For convenience, the normalization of the scaling and wavelet coefficients is omitted. To apply the inverse UDWT, we simply undo the forward lifting steps and divide the reconstructed signal by two for energy normalization.

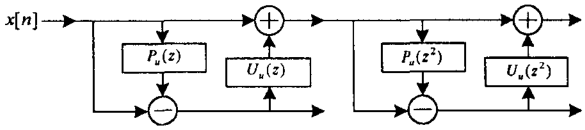

Figure 3. Structure of the forward undecimated lifting

The multiscale feature detection method is applied to capture local minimum points of the received envelope [12]. At most of scales, the indicators of features are located at the same position. Fig. 4 shows the indicators at each scale.

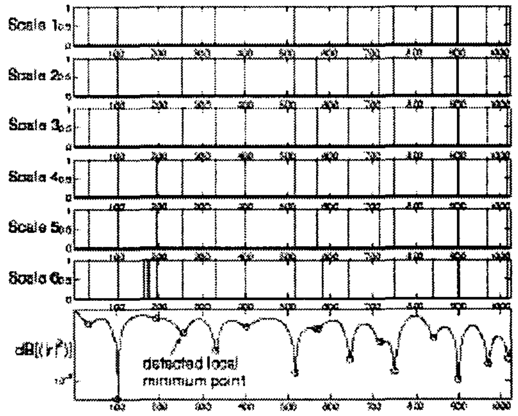

Figure 4. Indicators at each scale

For more smoothed speed estimation, past N local minimum points with weights w_i are used at time t.

$$\hat{v}(t)=\frac{k\,\lambda}{\frac{1}{N}\sum_{i=1}^{N} w_i\,\Delta t_i} \tag{8}$$

where Δt_i denotes the time difference between ($i-1$)-th and i-th local minimum points.

4. Simulations

The speed estimator based on undecimated lifting is applied to constant and variable mobile speeds in Figs. 5 and 6. The predict and update stages with 2 vanishing moments are used for the undecimated lifting. The received envelop is decomposed up to level 6. The past 10 local minimum points are used for weighted summation of time differences. For convenience, unit wavelength, $\lambda=1$ and 9 multipath rays ($N_s=9$) are assumed. k is empirically calculated as 0.6.

Figs. 5 and 6 show that the undecimated lifting based estimator is able to track both constant and variable speed profiles. Fluctuations at high speed could be reduced after post processing, such as moving average.

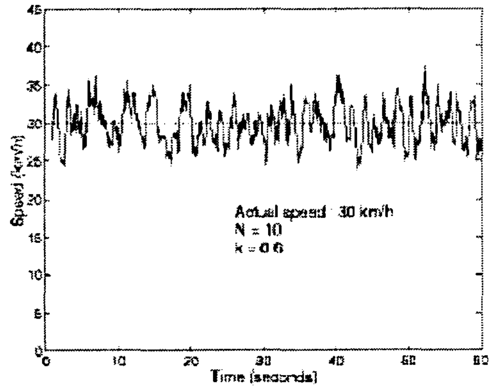

Figure 5. Estimated speed for a constant mobile speed

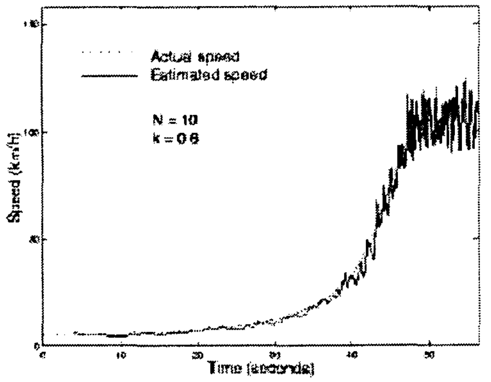

Figure 6. Estimated speed for a variable mobile speed

5. Conclusion

In a Rayleigh fading environment, the speed estimator based on the undecimated lifting instead of the WTMM is presented with the hope of practical implementation in wireless systems. Without additive noise, the proposed method is comparable to the WTMM speed estimator for both constant and variable mobile speeds.

Using multiscale feature extraction, the indicators at scales represent the local minimum points of the logarithm of the received signal envelope. The estimated speed is obtained from the time differences between the detected local minimum points caused by the multipath effect.

References

[1] Mottier, D., Castelain, D., A Doppler dstimation for UMTS-FDD based on channel power statistics, *Vehicular Technology Conference*, vol. 5, pp.3052 -3056, 1999.

[2] Ravi Narasimhan and D. C. Cox, Speed estimation in wireless systems using wavelets, *IEEE Transactions on Communications*, vol.47, no.9, pp. 1357-1364, Sept. 1999.

[3] Tai-Chiu Hsung, Daniel P.-K. Lun, and Wan-Chi Siu, Denoising by singularity detection, *IEEE Transactions on Signal Processing*, vol.47, no.11, pp.3139 -3144, Nov. 1999.

[4] W. C. Jakes, *Microwave Mobile Communications*, New York: Wiley, 1974.

[5] James K. Cavers, *Mobile Channel Characteristics*, Kluwer Academic Publishers, 2000.

[6] R. R. Coifman and D. Donoho, Translation-invariant de- noising, in *Wavelets and Statistics*, vol.103 of *Lecture Notes in Statistics*, pp.125-150, Springer-Verlag, New York, 1995.

[7] G. P. Nason and B. W. Silverman, Stationary wavelet transform and some statistical applications, Technical Report, Department of Mathematics, University of Bristol, Bristol, U.K., Feb. 1995.

[8] C. S. Burrus, R. A. Gopinath, and H. Guo, *Introduction to wavelets and wavelet transforms*, Prentice Hall, 1998.

[9] W. Sweldens, The lifting scheme: A custom-design construction of biorthogonal wavelets, *J. Appl. Comp. Harm. Anal.*, vol.3, no.2, pp.186-200, 1996.

[10] I. Daubechies and W. Sweldens, Factoring wavelet transforms into lifting steps, *J. Fourier Anal. Appl.*, vol.4, no.3, pp.247-269, 1998.

[11] Chang Soo Lee, Chan Kil Lee, and Kyung Yul Yoo, New lifting based structure for undecimated wavelet transform, *Electronics Letters*, vol. 36, no. 22, pp.1894 -1895, Oct. 2000.

[12] Hajj, H.M., T. Q. Nguyen, and Chin, R.T., On Multi-Scale Feature Detection Using Filter Banks, *29th Asilomar Conference*, vol.1, pp.70 -74, 1996.