Proceedings of ISAP'04, Sendai, JAPAN

MOBILE POSITIONING USING SPACE-DIVERSITY ANTENNAS FOR W-CDMA SYSTEM

Tsui-Tsai Lin
Department of Electronic Engineering
National United University
1 Lien Da, Kung-Ching Li, Miao-Li 360, Taiwan R.O.C.
Email: ttlincs@nuu.edu.tw

1. Introduction

In the United States of America, the Federal Communication Commission (FCC) mandated a Report and Order in October 1996 that cellular carriers must be able to identify a wireless caller's location within 100 meters at least 67 percent of the time. This mandate has to implement by October 1, 2001. Moreover, in a wireless communications networks, the vast benefits in location services, such as public safety, enhanced emergency services, locating sensitive billing, vehicle and fleet management, fraud management, and intelligent transportation system, are accelerating the importance and necessity of the mobile station (MS) positioning in a cellular communications system [1]-[2].

Commonly studied network-based method for determining the MS position is the angle-of-arrival (AOA) based positioning [3]. The AOA-based system employs triangulation techniques to determine the MS position through the use of antenna arrays. The MS position is uniquely defined by the intersection of two directional lines of bearing, which are formed by employing the array signal processing to calculate the angle of the MS with respect to the base station (BS). This technique requires a minimum of two stations (or one pair) to determine a position. Moreover, if an AOA-based system is used, BSs have to be changed in order to apply the AOA positioning to the existing networks. Great efforts in modifying the existing wireless system make it difficult to realize in practice. Another technique referred to time-of-arrival (TOA) positioning determines the MS position by the intersection of the distance circles, which are the measurements of the ranges between an MS and a BS [3]. Since the propagation time of the radio wave is directly proportional to its traversed range, the distance can be given by multiplying the propagation time to the light speed. It is obvious that the MS position can be uniquely determined by using at least three BSs. This method usually induces the disadvantage that precisely synchronized clocks for all transmitters and receivers are required. Otherwise, a microsecond timing error could lead to a 300-meter error in positioning. This worse performance makes it insufficient in practice.

BSs are typically designed to implement switch diversity scheme, with two antennas serving a sector of 120 degrees, to alleviate the performance degradation due to the fading channel. In this paper, a network-based positioning using the space diversity antenna array in a Code Division Multiple Access (CDMA) communications system is proposed. First, an AOA estimator consisting of a correlator to calculate the instantaneous cross-correlation between the array outputs, an accumulator to compute the averaging cross-correlation, and a phase detector to determine the MS AOA with respect to the BS. To further enhance the performance in AOA estimation, a multipath suppressor is then proposed to mitigate the effects of leakage multipaths due to lack of processing code (de-spreading code). Final, the resultant AOA is performed cooperating with the TOA measurement associated with the propagation time, obtained by the CDMA receiver, to derive the MS position. In the proposed scheme, only one BS is required to determine the MS position without significantly increasing the complexity load in implementation. If available, more BSs can be used for performance enhancement.

2. Proposed Angle-of-Arrival (AOA) Estimator with Multipath suppressor

In a wireless communications system, space diversity technique is widely used to alleviate the fading effect because of its simple and economical implementation. To achieve a reliable communication quality, the branch outputs are formed in such a fashion that the fading phenomena observed on the array outputs are statistically uncorrelated. In spite of the received signals from the

ISBN: 4-88552-207-2 C3055©IEICE

two branches fade independently, their corresponding phases received at the antennas are different and depend on both the impinging angle of source (MS) and the antenna locations. Since the positions of antennas can be exactly determined by the BS, the impinging direction of the MS with respect to the BS can be derived by analyzing the antenna outputs. According to characteristic of antenna array, the phase difference depending on the MS AOA can be expressed by the cross-correlation between the array outputs. That is, the AOA can be obtained based on the cross-correlation of the branch outputs.

The design of the proposed AOA estimator for the Third Group Partnership Project (3GPP) involves the following procedure. First, in the Wideband-CDMA (W-CDMA) system, the received signal is multiplied by a channelization code, an Orthogonal Variable Spreading Factor (OVSF) code, used to suppress the signals from the other users with different channelization codes. Then the resultant signal is sent to de-spreading processor to suppress the multipath signals introduced by environments. After de-spreading, the processed data associated with one of branches is multiplied by that of the other one to compute the instantaneous cross-correlation. In order to smooth the time variation of channel, an accumulator with an attenuator is then used within an observation period to form an averaging cross-correlation. Finally, according to the accumulator output along with simple manipulations, the AOA estimate of the MS can be derived by a phase detector. It is noteworthy that the attenuator, often referred to forgetting factor (FG), is utilized to describe the variation of instant cross-correlation. The corresponding value ($0<FG<1$) is determined according to the environment conditions, e.g., fast moving or slow moving MS. The overall architecture of the proposed AOA estimator is depicted in Figure 1.

In the case of a moderate value of signal-to-noise ratio (SNR), this processor with a proper observation period can achieve a better performance in AOA estimation. However, the large noise power will significantly degrade the performance and then will induce a poor accuracy in positioning. This is because that the phase information concealed in the cross-correlation cannot be correctly extracted from a few samples as noise power is large, i.e. low SNR. As a remedy, a longer observation period for increasing the number of samples is required to alleviate this degradation. On the other hand, to remedy the degradation in performance due to the strong multipaths, a multipath suppressor is proposed for further removing the residual multipath signals. In 3 GPP, spreading, consisting of channelization operation and scrambling operation, is utilized in the physical channels. The former is used to transfer data symbol into a number of chips. The number of chips per data symbol is called the Spreading Factor (SF). The later is a complexity value code, called as scrambling code. With the channelization, the data symbols, termed as I- and Q- branches, are independently multiplied with orthogonal variable SF (OVSF) codes. It is noteworthy that the channelization codes for different users are orthogonal to each other. With the scrambling operation, the resultant signals on I- and Q-branches are then multiplied by the scrambling code.

In the receiver, the reversal procedure is used to restore the data from the user of interest. First, the received data is multiplied by a scrambling code. The output data is then multiplied by the pre-determined channelization code. In accordance with the orthogonal characteristic of the channelization code, the data from the user of interest can be correctly obtained, while the signals from the others suppressed. Unfortunately, the multipaths with the same channelization code cannot be completely suppressed by the de-spreading processor. This is because that only part of the scrambling code is used to correlate the received data to obtain the data bits, e.g. 256 chips employed for the uplink Dedicated Physical Control Channel (DPCCH) in 3 GPP wireless cellular networks. Note that the length of scrambling code is 38400. The lack of de-spreading code will induce the residual multipath signals after the de-spreading processor. The leakage signals will result in confusedly calculating the phase between the branch outputs and then degrade the correctness of the MS positioning determination. As a remedy, a processor, called as multipath suppressor, for further attenuating the residual multipath signals by means of extending the processing code length is proposed.

In uplink DPCCH, a slot structure, as shown in Figure 2, consists of known pilot bits to support channel estimation for coherent detection, optional transport-format combination indicator (TFCI) bits, feedback information (FBI) bits, and transmit power-control (TPC) bits. The number of pilot bits with known patterns, configured by higher layers, is from three to eight. The phase difference among the pilot bits (± 1), hidden in the received data, can be aligned (compensated) by multiplying the de-scrambled data together with the pre-known pilot bits. Since the product of the de-scrambled data and the pilot bits will get rid of the effect of phases associated to the pilot bits, the phase-aligned data can be simultaneously processed during many bits. That is, the de-spreading processor can be performed on a few successive phase-aligned pilot bits to further attenuate the residual multipath signals. The corresponding schematic diagram is given by Figure 3. Note that the multiplier for phase alignment is swapped with pilot extractor for ease in implementation. From the figure, the multipath suppressor is composed of a pilot bit extractor used to locate the pilot bits for further processing, a phase aligning multiplier for compensating the phases among the pilot bits, and an accumulator for summing up the successive processed pilot bits.

An AOA estimator based on the space-diversity antenna array is found to achieve better performance as long as the multipaths are weaker than the direct path signal. In the presence of strong multipaths, this estimator exhibits severe degradation in performance. As a remedy, a multipath suppressor is used to mitigate the effect of residual multipaths. Simulations have shown the efficacy of the proposed method. Unfortunately, this method requiring two correlators for restoring the signal from the user of interest induces cost-inefficiency in implementation due to heavy complexity load. In this section, a novel architecture with only one correlator is proposed for mobile positioning. The procedures of the proposed algorithm, as shown in Figure 4, for AOA estimation in a wireless cellular system can be summarized as below:

(1) A switch with a period T_s is utilized to alternatively receive the signals from two branches.
(2) A de-spreading processor (de-scrambling and de-spreading processor) is used to restore the signals of interest, while the other signals suppressed.
(3) A serial-to-parallel operator is employed to assign the processed data to two branches.
(4) A multipath suppressor is used to further attenuate the residual multipaths in the outputs of the de-spreading processor and the corresponding results are reported to the correlator every T_{slot} seconds, with T_{slot} being the slot length 0.67 ms in 3GPP.
(5) A correlator is used to calculate the instantaneous cross-correlation between the branch outputs.
(6) An accumulator is utilized to alleviate the time-varying effect of channel.
(7) A phase detector is used to estimate the MS AOA according to the accumulator output at the observation instant T_o.

3. Computer Simulations

An example considered herein demonstrates the efficacy of the proposed multipath suppressor. The parameter settings in the simulation are based on the technical specification for 3 GPP and the number of pilot bits for processing is three (at least three pilot bits in DPCCH). An attenuator factor defined by P_{out}/P_{in}, with P_{in} and P_{out} being the input and output powers of processing samples, respectively, is used to evaluate the performance of the multipath suppressor. Note that more multipath signals will be suppressed from the processing data as the attenuator factor decreases. The corresponding results are shown in Figure 5. Obviously, the 3-bit multipath suppressor can further suppress (at least 5 dB) the residual multipath in the case of poor suppression. Although the proposed method fails to improve the performance obtained by the original one with better suppression, e.g., third sample, fortunately, the weak residua, as compared with the direct path signal, put less emphasis on AOA estimator, and will not significantly degrade the performance in AOA estimation.

To gain more insights, the performance in AOA estimation for 3 GPP is included to examine the efficacy of the proposed method under a multipath fading channel. A two-element array with three wavelengths inter-element spacing is employed. The carrier frequency of the impinging signals is centered at 1900 MHz. There are three paths in this test model: a direct path and two multipaths. The delays of two multipaths with the same power 0 dB are 976 (about 4 chips) and 20000 (about 77 chips) nano-seconds. The bit rate and sampling rate are both 3.84 MHz. The MS is 10 Km apart from the BS. Finally, the vehicle speed is 3 km/hr. We utilize the DPCCH data with spreading factor 256 to estimate the MS AOA. For performance evaluation, the detection probability is defined by the cumulative distribution function $CDF = F(x_0) = \sum f(x < x_0)$ (the probability of the event $\{x < x_0\}$), with $f(x)$

being the probability of the event x (detection error). The results are shown in Figure 6 for SNR (E_b/N_o) equal to 4 and 6 dB (corresponding chip power to noise ratio –20 and –18 dB, respectively). The detection probability of the original method, presented in dashed line, is also depicted for comparison. Clearly, the AOA estimator with the multipath suppressor significantly outperforms that of the original one. This implies that the performance degradation due to strong multipaths can be alleviated by means of the multipath suppressor, especially for low SNR.

4. Conclusion

In this paper, we proposed a novel AOA estimator with multipath suppressor for the W-CDMA system. Only one BS is required to determine the MS position without significantly increasing the complexity load in implementation. Numerical results demonstrate the efficacy of the proposed scheme in mobile positioning.

Reference:

[1] U.S. Patent#5,614,914, "Wireless Telephone Distribution System with Time and Space Diversity Transmission for Determining Receiver Location."

[2] J. Caffery, and G.L. Stuber, "Subscriber Location in CDMA Cellular Networks," *IEEE Trans. Veh. Technol.*, vol. 47, no. 2, pp. 406-416, May 1998.

[3] T.S. Rappaport, J.H. Reed, and B.D. Woerner, "Position Location Using Wireless Communications on Highways of the Future," *IEEE Commun. Mag.*, pp. 33-41, October 1996.

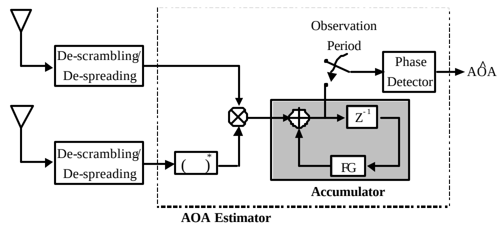

Figure 1: Block diagram of proposed AOA estimator.

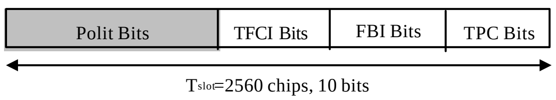

Figure 2: Slot structure of uplink DPCCH.

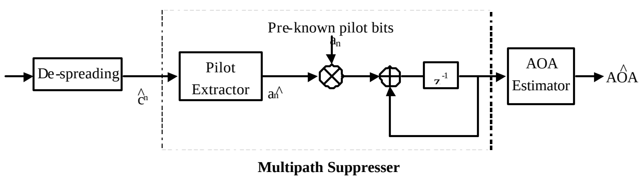

Figure 3: Block diagram of multipath suppressor.

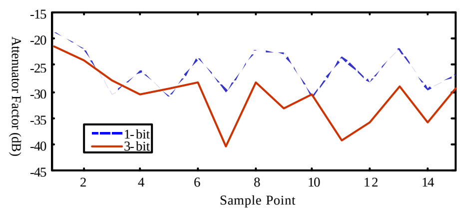

Figure 5: Performance of multipath suppressor.

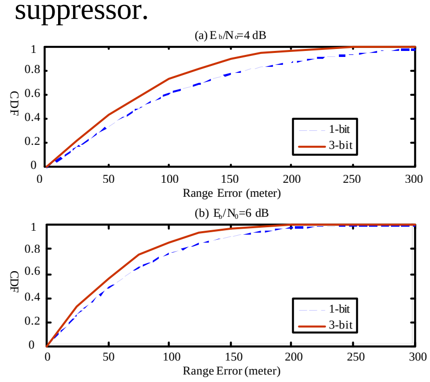

Figure 6: Performance of AOA estimator with multipath suppressor.

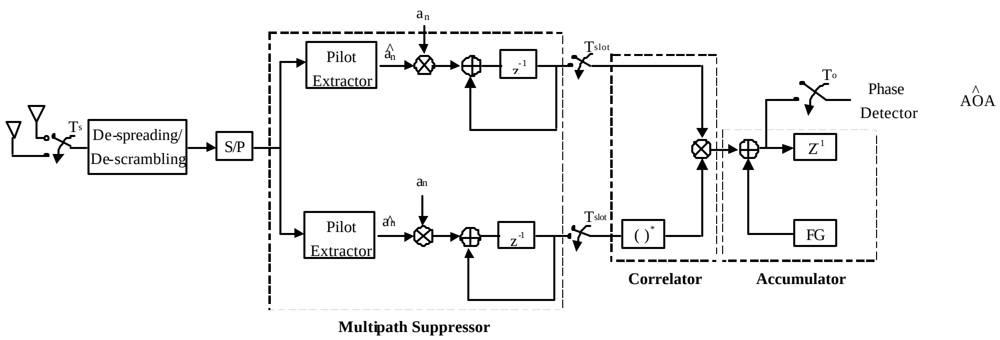

Figure 4: Block diagram of proposed AOA estimator with multipath suppressor.