High Resolution Time Delay Estimation Technique for Position Location

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Abstract: This paper analyses the performance of PE-IPDL technique for the wireless mobile position location, which have been considered as a major candidate for 3GPP position location due to its capability in mitigating the hearability problem and DOP problem. To improve the location performance of PE-IPDL, this paper introduces the high-resolution estimation technque for the first arrival multipath delay, and simulation results verify its superiority. For a systematic analysis of above location method, its perfomances are exploited by obeying the CODIT channel model specially bad urban channel environment. Simulation results verify its efficiency of enhancing the degree of accuracy in positioning.

1. Introduction

Recently the wireless position location accommodates a great deal of attention due to its potential extension to E-commerce, emergency service and other location based public services [1]. Towards this, since it does not need the support of GPS satellites, the network based positioning solution has been preferred to be deployed. And various relevant positioning schemes have been introduced and their performances are verified throughout many papers.

According to the network based wireless positioning solution, it needs the accurate relative time-delay difference, i.e., TDOA (Time Delay of Arrival), those are estimated at handset over prescribed time interval by observing received signal incoming from several adjacent basestations. But it is worth while to mention that small amount of mismatch between original and estimated TDOA values gives rise to severe positioning error. Even in bad GDOP environment or bad urban channel situation under the rich scattering, this positioning error becomes more serious. To mitigate this, this paper introduces the high resolution time delay estimation technique [2] which can be adopted to estimate the first arrival time delay for the enhanced network based positioning system.

Among many network based positioning solutions for 3GPP (W-CDMA), due to its superior robustness withstanding the hearability problem on downlink, the IPDL (Idel Period on Down Link) technique [3][4] has been considered as a major candidate without any support of GPS satellites. Furthermore to alleviate the positioning error in the presence of the hearability problem, GDOP (Geometric Dilution of Position) and near-far problem, the IPDL using PE (Positioning Element) named as PE-IPDL [5][6] has been optionaly recommended.

The paper is organized as follows. Section 2 explains the principle of PE-IPDL method. Section 3 introduces the high resolution time delay estimation technique. And the superior performance of the proposed method is verified throughout computer simulations, and results are discussed in Section 4. Finally, Section 5 contains the conclusions.

2. Principles of PE-IPDL

The PE-IPDL is one of wireless positioning methods for 3GPP. In oder to support the action of IPDL, PEs are located near serving BS. The major role of PEs is to mitigate the hearability problem, the near-far problem and the DOP problem which are frequently experienced in realistic situation. Also PE-IPDL method gains an advantage over other existing methods in certain environments where other geometric reference points, i.e. basestations, satellites, etc., are not visible to the handset, for example at the edge of cellular coverage, indoors, and in rural areas.

During the idle period, synchronized PEs transmit their own pre-determined pilot signals together with overhead informations. Besides the principle location of BSs, pre-assigned geometric coordinates are broadcasted to the handset from the primary BS a priori.

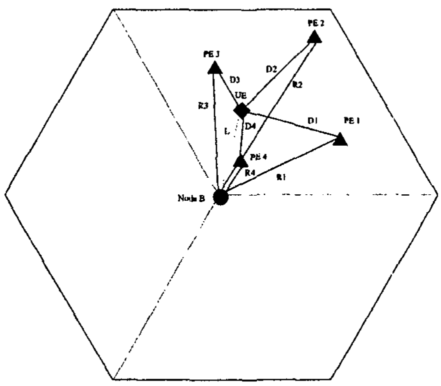

Figure 1 : Interactions between BSs and PEs

Here in order to regenerate the pilot signals associated to the primary BS, PEs are required to follow 3 step cell search procedure to synchronize with the serving basestation. Then PE should acquire its own identifier code and relevant system parameters for managing IPDL. Figure 1 shows the configuration of PE-IPDL, and interactions between PEs and serving BS. Here, R and D denote the distance between the basestation to each PE and between the mobile to each PE respectivley. In Fig. 1, L is the distance between the basestation and mobile and c is denoted as the speed of light.

Referring to Fig. 1, while handset is in idle period, the timing diagram of receiving idle frame from serving BS and existing four PEs are depicted in Fig. 2. At the handset, a series of OTDOA (Observed Time Difference of Arrival) can be measured. For example, the OTDOA from the fourth PE can be expressed as $R_4/c + D_4/c - L/c$. Here it is noticible that the exact distance R_4 between the basestation and PE4 is a priori known and every OTDOA values contain L/c. Thus actual TDOA measurements, i.e. arrival time difference from serving BS and PEs $(D_4 - L)/c$, can be retrieved for OTDOA values with the help of RTD(Relative Time Difference) measurements observed by LMU(Location Measurement Unit). Consequently, the location of handset can be estimated from recovered TDOAs by adopting various exisiting opitmization techniques.

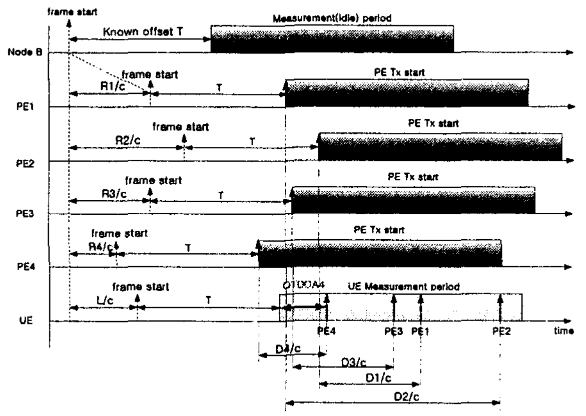

Figure 2 : Receiving timing diagram at handset in idle period.

3. High resolution time delay estimation technique

One of major obstacles degrading the performance of wireless positioning is originated from the difficulty of accurate estimation of first arrival. In realistic situation such as in bad urban scattering environment, multipath components at second arrival afterward could have dominant power. Observing the output level of the matched filter, the second arrival or the afterward would be chosen mistakenly as the first incoming time delay. In order to avoid this kind of happening, this paper introduces the high resolution delay estimation scheme explained as follows.

Provided that the synchronized CPICH (Common Pilot Channel) signal $s(t)$ is transmitted from adjacent basestation and PEs, and multipath fading channel is denoted as $h(t)$. The received signal at the handset, $y(t)$, has the form of the following

$$y(t) = s(t) * h(t) = s(t) * \left\{ \sum_{i=1}^{m} a_i \delta(t - \tau_i) \right\} = \sum_{i=1}^{m} a_i s(t - \tau_i) \quad (1)$$

where m is the number of multipaths according to local scatteres, and its corresponding channel parameter, a_i ,is presume to have the nakagami-m distribution. The signal after matched filter, i.e., despreading Eq. (1) using a certain primary PN sequence assigned to basestation, can be expressed as

$$y_{ds}(t) = \sum_{i=1}^{m} a_i r_s(t - \tau_i) \quad (2)$$

where $y_{ds}(t)$ is the correlator output and $r_s(t - \tau_i)$ is the inherent correlation function of primary PN sequence. Then Fourier transform of Eq. (2) can be written as

$$Y_{ds}(\omega) = \sum_{i=1}^{m} a_i R_s(\omega) e^{-j\omega\tau_i} \quad (3)$$

Dividing both sides of Eq. (3) with $R_s(\omega)$ gives rise to the following $K(\omega)$ as the step of deconvolution such that

$$K(\omega) = \frac{Y_{ds}(\omega)}{R_s(\omega)} = \sum_{i=1}^{m} a_i e^{-j\omega\tau_i} \quad (4)$$

where $K(\omega)$ is defined as the deconvolved function. Now a series of samples in frequency domain can be obtained by sampling $K(\omega)$ with the interval $\Delta\omega$ given by

$$K(n\Delta\omega) = \sum_{i=1}^{m} a_i e^{-jn\Delta\omega\tau_i} \quad (5)$$

Using sampled data obtained form Eq. (5), a hermitian Toeplitz matrix K can be constructed such that

$$K = \begin{bmatrix} K(0\Delta\omega) & K(0\Delta\omega) & \cdots & K(0\Delta\omega) \\ K(-1\Delta\omega) & K(0\Delta\omega) & \cdots & K((N-1)\Delta\omega) \\ K(-2\Delta\omega) & K(-1\Delta\omega) & \cdots & K((N-2)\Delta\omega) \\ \vdots & \vdots & \ddots & \vdots \\ K(-N\Delta\omega) & K(-(N-1)\Delta\omega) & \cdots & K(0\Delta\omega) \end{bmatrix} \quad (6)$$

In (6) matrix K can be decomposed into

$$K = SBS^H \quad (7)$$

where H means the hermitian operator matrix, and K has the rank of m because sample sequence as in (5) is composed of m eigen-modes. Thus matrix K has m nonzero eigenvalues. In (7) S is the Vandermonde type matrix with the size of $(N+1)\times m$ whose components are constructed from eigen-modes in (5), and B is the $m \times m$ diagonal matrix whose components are fading parameters as in (1), those are given by

$$S = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ e^{j\Delta\omega\tau_1} & e^{j\Delta\omega\tau_2} & \cdots & e^{j\Delta\omega\tau_m} \\ e^{2j\Delta\omega\tau_1} & e^{2j\Delta\omega\tau_2} & \cdots & e^{2j\Delta\omega\tau_m} \\ \vdots & \vdots & \ddots & \vdots \\ e^{Nj\Delta\omega\tau_1} & e^{Nj\Delta\omega\tau_2} & \cdots & e^{Nj\Delta\omega\tau_m} \end{bmatrix} \quad B = \begin{bmatrix} a_1 & 0 & \cdots & 0 \\ 0 & a_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & a_m \end{bmatrix} \tag{8}$$

Provided that eigenvalues of matrix K are arranged as the descending order, and let $\{\lambda_i\}_{i=m+1}^{N+1}$ being zero values, it can easily shown that the following equation is true.

$$SBS^H e_k = \lambda_k e_k = 0, \qquad k = m+1, \cdots, N+1 \tag{9}$$

where e_k is the eigenvector of matrix K associated to eigenvalue λ_k. Multiplying B^H and S^H on both sides at Eq. (9) gives rises to

$$[B^H S^H SB] \cdot S^H e_k = 0 \tag{10}$$

In (10), let us denote $m \times m$ matirx $B^H S^H SB$ as M, since this matrix is full rank then there exists its inverse. After multiplying M^{-1} on both sides of the above equation, Eq. (10) can be rewritten as

$$S^H e_k = 0, \quad k = m+1, \cdots, N+1. \tag{11}$$

Here as in (11) since the colum vectors of matrix S denoted by $\{V_1, V_2 \cdots V_m\}$ are orthogonal to the eigenvectors $\{e_k\}_{k=m+1}^{N+1}$, it can be stated that the subspace spanned by the eigenvectors $\{e_k\}_{k=1}^{m}$ is identical to that spanned by the row vectors of matrx S. Therefore eigenvectors $\{e_k\}_{k=1}^{m}$ associated to nonzero eigenvalues can be expressed as the linear combination of column vectors of S, i.e.,

$$e_i = \sum_{i,k=1}^{m} c_{i,k} V_i, \quad i = 1, \cdots, m. \tag{12}$$

Let us denote the matrix composed of eigenvectors corresponding to non-zero eigenvalues define as E of the size $(N+1) \times m$ given by

$$E = [e_1 \quad e_2 \quad \cdots \quad e_m]. \tag{13}$$

With the help of (8) and (12), the matrix E can be rewritten as the matrix S and $m \times m$ linear combination matrix C.

$$E = SC \tag{14}$$

where $(i,j)^{th}$ component of C is $c_{i,j}$ in (12). Also matrices E_1 and E_2 are generated by eliminating the top row and the bottom row vector E respectively, i.e,,

$$E_1 = \begin{bmatrix} e_0^{(1)} & e_0^{(2)} & \cdots & e_0^{(m)} \\ \vdots & \vdots & \ddots & \vdots \\ e_{N-1}^{(1)} & e_{N-1}^{(2)} & \cdots & e_{N-1}^{(m)} \end{bmatrix} \quad E_2 = \begin{bmatrix} e_1^{(1)} & e_1^{(2)} & \cdots & e_1^{(m)} \\ \vdots & \vdots & \ddots & \vdots \\ e_N^{(1)} & e_N^{(2)} & \cdots & e_N^{(m)} \end{bmatrix} \tag{15}$$

Using (12), the above matrices can also expressed in terms of S_1 and D as follows

$$E_1 = S_1 C, \quad E_2 = S_1 DC \tag{16}$$

where $N \times m$ matrix S_1 and $m \times m$ diagonal matrix D are denoted as

$$S_1 = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ e^{j\Delta\omega\tau_1} & e^{j\Delta\omega\tau_2} & \cdots & e^{j\Delta\omega\tau_m} \\ e^{2j\Delta\omega\tau_1} & e^{2j\Delta\omega\tau_2} & \cdots & e^{2j\Delta\omega\tau_m} \\ \vdots & \vdots & \ddots & \vdots \\ e^{(N-1)j\Delta\omega\tau_1} & e^{(N-1)j\Delta\omega\tau_2} & \cdots & e^{(N-1)j\Delta\omega\tau_m} \end{bmatrix} \tag{17}$$

$$D = \begin{bmatrix} e^{j\Delta\omega\tau_1} & 0 & \cdots & 0 \\ 0 & e^{j\Delta\omega\tau_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & e^{j\Delta\omega\tau_m} \end{bmatrix} \tag{18}$$

Referring (16)-(18), interestingly the exponents of general eigenvalues of E_1 and E_2 contain the time delay components associated to multipaths. Therefore, once matrices E_1 and E_2 are constructed from eigenvectors associated to nonzero eigenvalues of observable matrix K, generalized eigenvalues λ_i, $i = 1 \rightarrow m$, of E_1 and E_2 produce the time delay components τ_i, i.e., $imag\{\lambda_i / \Delta\omega\}$. Thus the first arrival can be chosen as the least value among estimated time delay components.

4. Simulation Results

In order to verify the performance of PE-IPDL employing the proposed time delay estimation technique, we consider the environment depicted in Fig. 3(a) where a BS and two PEs are existing in certain sector. Here the serving BS and PEs are collocated in the fashion of triangle. In Fig. 3(a) the star denotes the PE and the filled circle means the BS. Figure 3(b) shows the pilot signal generation block which are introduced in W-CDMA specification. Here the scrambling code for each CPICH is determined by the primary Gold code defined in [7]. To simulate the channel, the urban channel obeys the modified CODIT model is utilized which is specified in [8], and also the propagation loss is set on the basis of Hata model [9].

Figure 4 shows the performance of proposed channel estimation technique including time delay estimation. Here the number of scatters is 20, and its delay profile is shown in upper part in Fig. 4. Lower part in Fig. 4 shows the estimated delay profile. It can be easily seen that the original and the estimated have the high degree of similarity. Figure 5 and 6 illustrates the performance of PE-IPDL employing the proposed high resolution time delay estimation (HRTDE) scheme by varying Tx power. In Fig. 5 and 6, the dotted line corresponds to the performance with using conventional first arrival estimation, and the solid line indicates that of using HRTDE technique. According to simulation results, it can clearly notice that the capability of

PE-IPDL employing the proposed HRTDE method becomes greatly improved.

5. Conclusions

In this paper, we analyzed PE-IPDL method proposed in 3GPP as the network based positioning solution with employing the proposed HRTDE method to estimate the time delay of the first arrival. Along with the capability associated to PE-IPDL of mitigating the hearability, the DOP and the near-far problem, our proposed method gives the accurate estimate of time delay corresponding to the first arrival. Simulation results show the performance improvement of PE-IPDL with great extent. Thus, PE-IPDL with using the proposed HRTDE becomes more robust to impairments invoked in realistic situation.

Acknowledgement

This work was supported by Korea Research Foundation Grant(KRF 1999-E00230)

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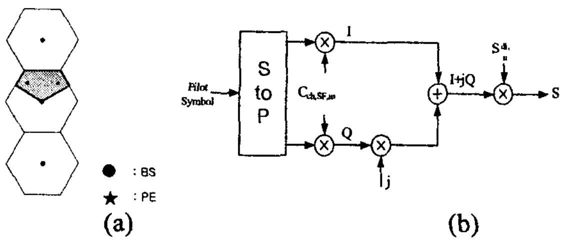

Figure 3 : Environment and pilot signal generation block for simulation

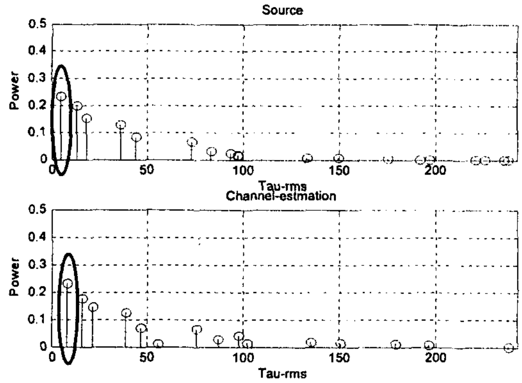

Figure 4 : Performance of the proposed channel estimation technique

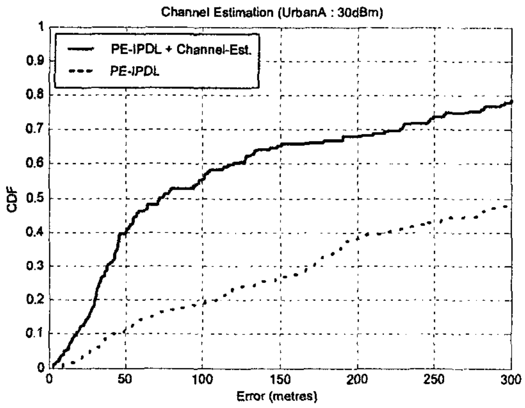

Figure 5 : Performance of PE-IPDL (Tx power: 30dBm) together with the proposed HRTDE scheme

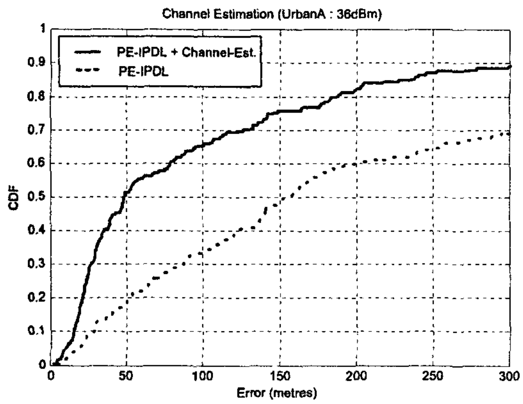

Figure 6 : Performance of PE-IPDL (Tx power: 36dBm) together with the proposed HRTDE scheme