Mobile Terminal Positioning Using Data Symbols to Mitigate the Influence of Noise in Multi Carrier Modulation

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***Abstract*: Positioning service in down-link cellular mobile system is expected. In the positioning of multi carrier modulation, the location of the mobile terminal (MT) is estimated by using the correlation of the pilot symbol known to MT. However, the accuracy of the detected location is not always sufficient in a multipath fading channel, since the received signal-to-noise power ratio (SNR) of the desired first path sometimes becomes low. In this paper, we propose a MT positioning method in which not only pilot symbols but also data symbols are used to mitigate the influence of noise in multi carrier modulation. We evaluate the proposed positioning method by computer simulation. As a result, we show the proposed method can improve the location detection probability when the data symbols are correctly detected.**

1. Introduction

W-CDMA and Cdma2000 service as the 3rd generation mobile communication systems have been started and received much attention because not only voice traffic but also various types of data traffic such as moving pictures can be transmitted.

As one of the various services, positioning service in cellular mobile system is expected because it can be applied for many applications in the 3rd and 4th generation mobile communication systems. In the United States, Federal Communications Commission (FCC) has planned to make it obligatory to equip the MT with the positioning function since 2001 in incremental steps. Some studies propose the methods using global positioning system (GPS) in the MT [1][2]. However, in the case of urban area, it is difficult to decide the location of MT because there are many high buildings in urban area and MT receives weak signals from GPS satellites. Therefore, the positioning method using a cellular system itself is needed. As the positioning method based on the cellular system, time of arrival (TOA) or time difference of arrival (TDoA) has been so attractive because the performance of TOA or TDoA is better than that of angle of arrival (AOA)[3]. In the recent researches, the positioning methods using TOA have been studied extensively[4]-[6].

In outdoor environment in the cellular system, the performance of positioning using W-CDMA and OFDM in up-link and down-link is evaluated [7]. In the case of positioning in up-link when the same frequency is used in multi cell environment, it is necessary for the MT in one cell to transmit the high-power positioning signal to the base station (BS) in more than two adjust cells. Therefore, serious co-channel interference (CCI) occurs. However, in down-link, since each BS transmits the common pilot channel which can be used for location detection as well as channel estimation, additional interference does not occur. Accordingly, the positioning in down-link is preferred.

In the 4th generation mobile communication system, it is expected that broadband frequency resource is used because the multimedia traffic is further increased. When we use broadband frequency resource, frequency selective fading might occur. In order to mitigate the influence of frequency selective fading, a multi carrier modulation scheme has been focused on. Accordingly, the positioning method using a multi carrier modulation in down-link should be considered. Although we can consider the positioning method combined with other schemes such as DS-CDMA only for positioning, the circuit configuration should be less complex.

When we decide the location of the MT by using a multi carrier modulation, the location of the MT is estimated by using the correlation of the pilot symbols known to MT. Since the pilot symbols are affected by noise, the pilot symbol should be used as many as possible to mitigate the influence of noise. However, BS can not transmit too many pilot symbols only for positioning because the overhead of the signal is increased.

In this paper, we propose a MT positioning method in which not only pilot symbols but also data symbols are used to mitigate the influence of noise in multi carrier modulation. In the case where the data are transmitted by a packet frame, the packet frame has a cyclic redundancy check (CRC) code for automatic repeat request (ARQ)[8]. In ARQ, if error is detected by CRC, the receiver requests the transmitter to retransmit data. In the case of no error, the correctly decoded data are obtained. In other words, data symbols can be regarded as pilot symbols if no error occurs. Accordingly, the number of pilot symbols is increased virtually and the influence of noise can be mitigated at the MT. We evaluate the proposed positioning method by computer simulation. As a result, we show the proposed method can improve the location detection probability when the data symbols are correctly detected.

2. The positioning method using a multi carrier modulation

In this section, we describe the positioning method by using a multi carrier modulation. As an example of a multi carrier modulation, we use OFDM [7]. If we decide the location of MT by using an OFDM symbol, we can use the property of cross correlation of an OFDM pilot symbol in the time domain. If we assume that the MT

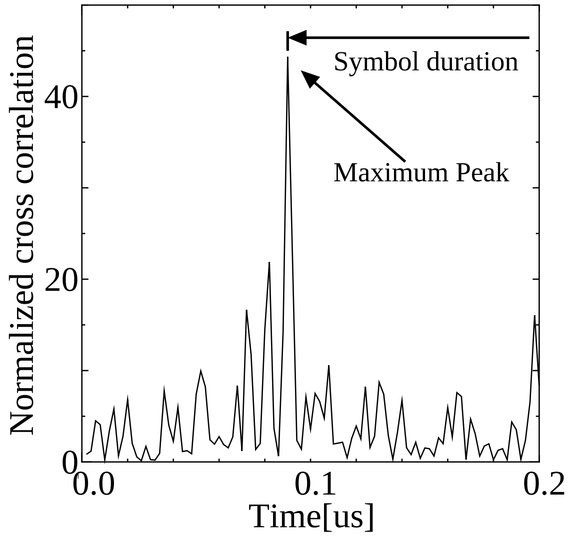

Figure 1: The example of cross correlation using OFDM.

knows the pilot signal transmitted from each BS in advance, MT calculates the cross correlation between the received pilot OFDM signal and the pilot OFDM signal transmitted from each BS. The period of correlation is equal to the one OFDM symbol.

In the case of using QPSK on each subcarrier, the signal for the time domain can be calculated in the I and Q parts independently. When we assume $j(1 \leq j \leq K)$ as pilot number, the cross correlation coefficient $R(j)$ of the pilot number j is represented by

$$R(j) = \int_0^N Ar_I(t)A_I(t)dt + \int_0^N Ar_Q(t)A_Q(t)dt \quad (1)$$

where $Ar_I(t)$ and $Ar_Q(t)$ are the amplitudes of the transmitted signal that MT knows in advance, $A_I(t)$ and $A_Q(t)$ are amplitudes of the received signals and N is the symbol duration. Since a time domain signal is scattered, the equation (1) can be rewritten as

$$R(j) = \sum_{i=0}^{N-1} Ar_I(i)A_I(i) + \sum_{i=0}^{N-1} Ar_Q(i)A_Q(i). \quad (2)$$

After that, the cross correlation coefficient $R(j)$ of the j symbol is added up by the K symbols. Fig. 1 shows the example of cross correlation using OFDM. As shown in Fig. 1, the cross correlation has the peak at the beginning of the symbol. The peak shows the arriving time of the path. Accordingly, if MT knows the time when BS began to transmit the pilot symbols, the distance from each BS to MT is calculated by the arrival time of the path. Based on the distance from each BS to MT, the location of MT is estimated. This process is done between each BS and MT. Also, this scheme can be applied to multi carrier CDMA(MC-CDMA).

In the case of the actual channel, noise causes the error of the estimated beginning of the symbol. In order to mitigate the influence of noise, we should use many pilot symbols. However, BS can not transmit too many

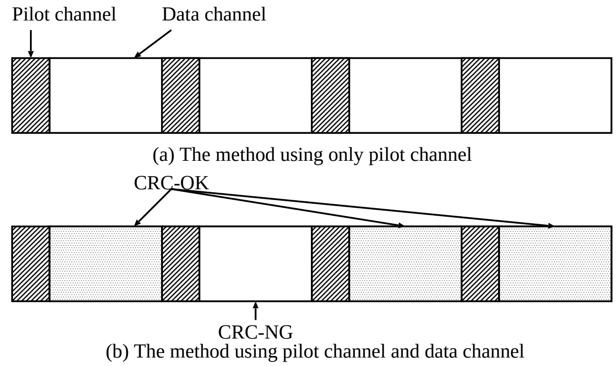

Figure 2: The frame utilization in the proposed method.

pilot symbols only for positioning because the channel capacity is decreased.

3. The Proposed Method

In the previous section, we discussed the influence of noise for positioning. Here, in order to mitigate the influence of noise, we propose to use not only pilot symbols but also data symbols. In the case where the data are transmitted by a packet frame, the packet frame has a CRC code for ARQ [8]. In ARQ, in the case of no error, the correctly decoded data are obtained. In other word, data symbols can be regarded as pilot symbols if no error occurs. Fig. 2 shows the frame utilization in the proposed method. In Fig. 2, only the pilot symbols are used in the conventional method. However, in the proposed method, not only the pilot symbol but also data symbols are used. Also, in the proposed method, only the error free decoded data symbols by CRC are utilized. Accordingly, it is possible that influence of noise is mitigated because the number of pilot symbols is increased by using data symbols virtually. Additional pilot symbols aren't needed in the proposed system. Therefore, the channel capacity is not decreased.

Fig. 3 shows the operation in the proposed method. First, pilot channel(PICH) and data channel(DCH) are separated in the received signal. Secondly, in PICH, the channel is estimated and the first path timing is detected collaterally. Next, data on DCH are demodulated by estimated channel state information and demodulated data are decoded by CRC. In the case of no error, error free data are regarded as the pilot symbols known to both transmit and receive sides. Therefore, these error free data can be applied to equation (2) and the first path timing is detected. By using the first path timing detected in both PICH and DCH, TOA/TDoA process is done and the location of MT is estimated.

4. Simulation results

We evaluate the performance of the proposed system by the computer simulation. As shown in Fig. 4, our simulation model has three BSs and consists of hexagonal cells with the radius of 500[m]. Also, MTs are located inside of a gray circle with radius of 300[m] randomly. In Figs. 8, 9 and 11, when the positioning error is

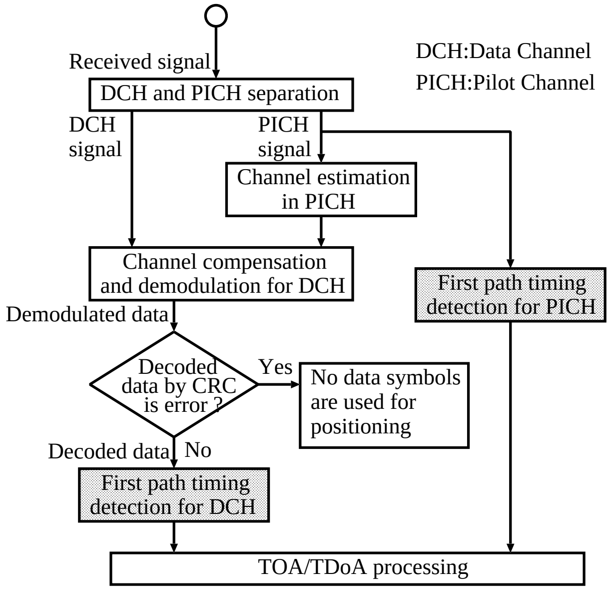

Figure 3: The operation in the proposed method.

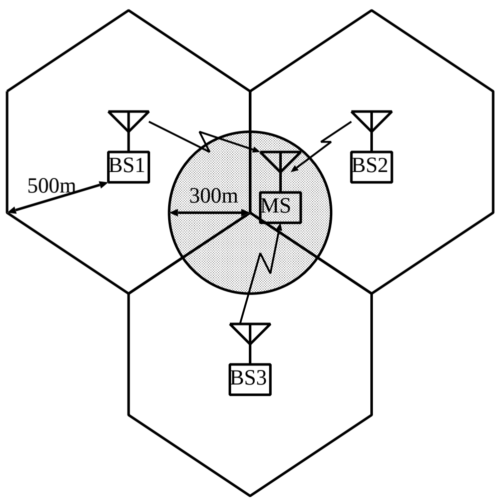

Figure 4: System model.

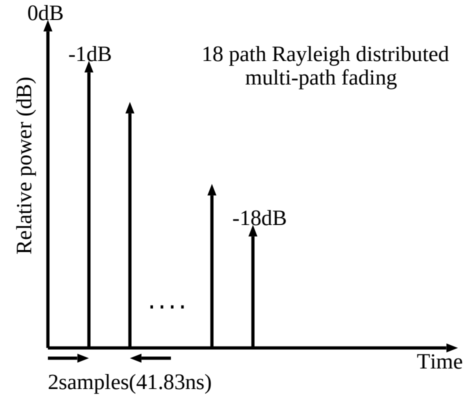

Figure 5: Channel model.

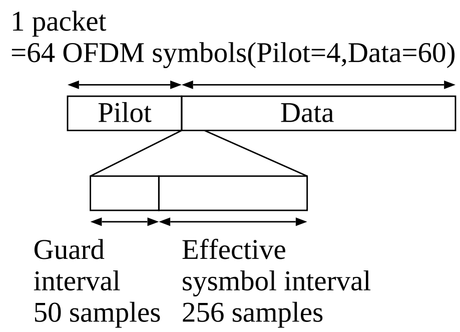

Figure 6: Packet structure.

less than 50[m], we consider that positioning is successful [9]. Table 1 shows the simulation parameters. We assume a carrier frequency of 2[GHz]. In this simulation, OFDM as a multi carrier modulation is used and the QPSK modulation scheme is used for a subcarrier modulation. Also, we assume an 18-path Rayleigh distributed multipath fading channel as shown Fig. 5. Shadowing is not considered except for the case as shown in Fig. 9. The power delay profile is a general exponential decay model and the vehicular test environment model in [10] is used as a path loss model. Path loss L [dB] is

$$L = 40 \times (1 - 4 \times 10^{-3} \times \Delta h_b) \times 10 \log_{10}(R) \\ -18 \times \log_{10}(\Delta h_b) + 21 \times \log_{10}(f) + 80[dB] \quad (3)$$

where R is a distance[km] between BS and MT, f is a carrier frequency and Δh_b is a base station antenna height[m] measured from the average rooftop level. In this simulation, we assume that Δh_b is 15[m]. Fig. 6 shows the packet structure. One packet is composed of 4 pilot symbols and 60 data symbols.

Also, in this paper, we use the path search algorithm in the conventional and proposed system [7]. In this section 2, we showed the method of regarding the maximum peak of the normalized cross correlation as the arriving time of the first path. However, in the method of using the maximum peak, the first path timing may not be detected correctly by multipath fading. Accordingly, by setting the appropriate threshold for the value of the normalized cross correlation, it is expected that the probability to estimate the first path timing correctly is increased. Fig. 7 shows the example of the normalized cross correlation applied to the path search algorithm. As shown in Fig. 7, in the case of using the maximum peak, the second path timing is detected. However, in the case of using the path search algorithm, the time of the first normalized cross correlation above the threshold is regarded as the arriving time of the first path. Consequently, the first path timing is estimated correctly compared with the system without the path search algorithm. Based on the received SNR, the threshold is set appropriately.

4.1. The performance of the proposed system

Fig. 8 shows the success rate versus transmit power where we set that the allowable positioning error is less than 50[m]. Transmit power shows the power transmitted from each BS. Also, we assume the number of suc-

Table 1: Simulation parameters

Modulation method	QPSK/OFDM
Number of subcarriers	64
Number of FFT points	256
Guard interval	20[%] of symbol duration
Symbol duration	6.4 μ s
Channel model	18 path Rayleigh fading
Doppler frequency	10 Hz
Noise power	-95[dBm]
Channel coding	Convolutional code (R=1/3,K=9)
Channel decoding	Soft decision viterbi decode
Shadowing	Log-normal distribution (only Fig.9)
Log-standard deviation	10[dB]

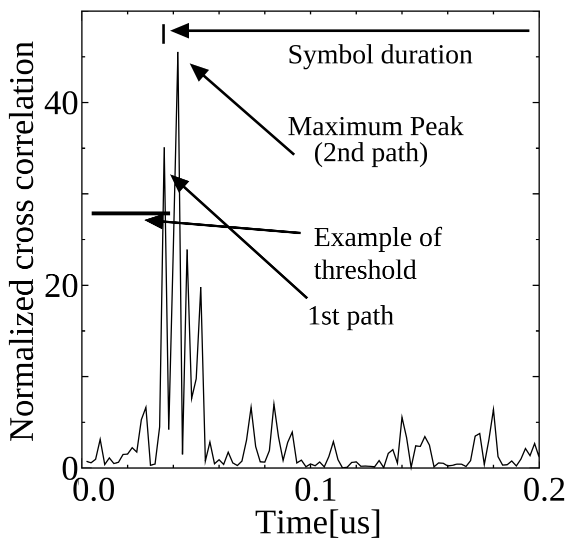

Figure 7: The example of cross correlation.

cessive packet is one. As shown in Fig. 8, the success rate in the proposed method is better than that of the conventional method above 25[dBm]. To explain the reason, we show the average packet error rate (PER) in Fig. 8. At the transmit power of 25[dBm], the average PER is about 0.4. This leads to increase the probability to utilize the data symbols in a packet in the proposed system above 25[dBm]. Accordingly, compared with the conventional methods, the symbols for positioning are increased and the influence of noise can be mitigated.

4.2. The performance of the proposed system in the case of shadowing

Fig. 9 shows the success rate versus transmit power in the case of shadowing where we set that the allowable positioning error is less than 50[m]. The number of the successive packet is one. As shown in Fig. 8, compared with the conventional method, the success rate in the proposed method is improved above 42[dBm]. This is because, as is the case with Fig. 8, the symbols for positioning are increased and the influence of noise can be mitigated.

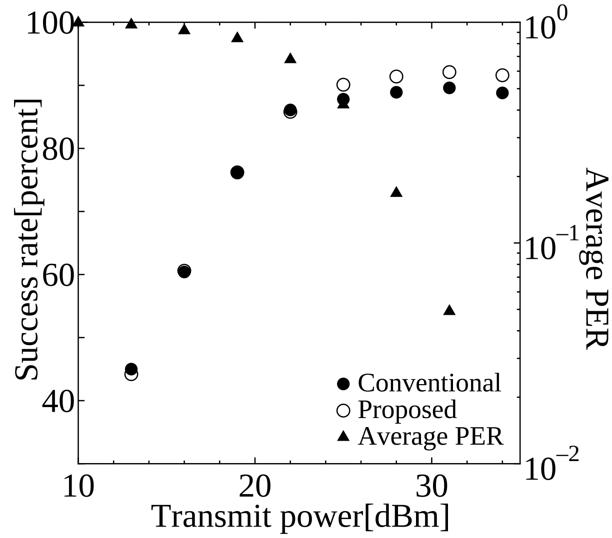

Figure 8: The success rate versus transmit power in the case of no shadowing where we set that the allowable positioning error is less than 50[m].

4.3. The performance of the proposed system for the position

All the while, MTs are located inside of a gray circle with radius of 300[m] randomly as shown in Fig. 4. However, we expect the success rate changes depending on the position in a gray circle. Therefore, in this section, we evaluate the conventional and proposed method in area A and area B as shown in Fig. 10. Area A is within 50[m] radius from center in 3 cells and area B is within no fewer than 250[m] and nor more than 300[m] radius from center in 3 cells. Fig. 11 shows the success rate versus transmit power for the position in the case where we set that the allowable positioning error is less than 50[m]. As shown in Fig. 11, the success rate in the proposed system is better than that in the conventional system above 25[dBm] in area A and above 28[dBm] in area B. This is because, as shown in Figs. 8 and 9, the symbols for positioning are increased and the influence of noise can be mitigated. Also, compared with the success rate in area B, the success rate in area A shows a good performance under 25[dBm]. Since the probability to use the packet from some BSs having large path loss is increased in area B compared with that in area A, it is more difficult to detect the first path timing correctly.

5. Conclusions

We have proposed the positioning method in downlink and multi carrier modulation. In the proposed method, to mitigate the influence of noise, we use not only pilot symbols but also error-free data symbols by CRC. By computer simulation, we show the success rate is improved in the proposed system. Therefore, it is shown that the proposed system can mitigate the influence of noise and can improve the location detection probability.

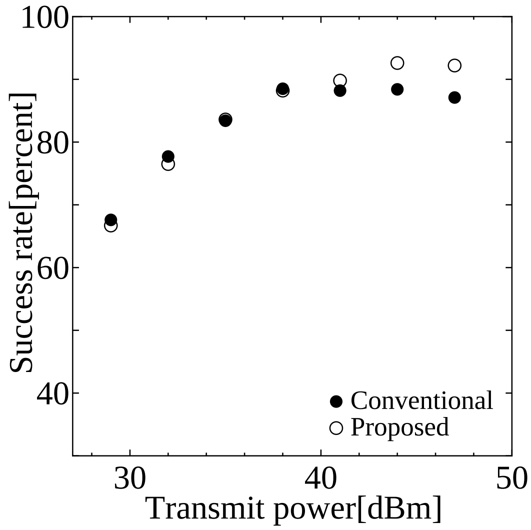

Figure 9: The success rate versus transmit power in the case of shadowing where we set that the allowable positioning error is less than 50[m].

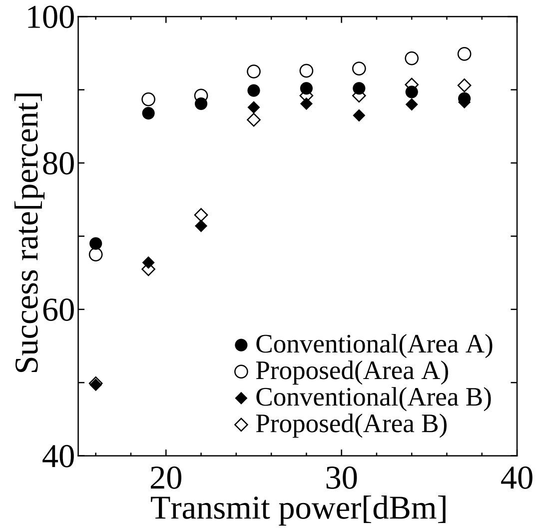

Figure 11: The success rate versus transmit power for the position in the case where we set that the allowable positioning error is less than 50[m].

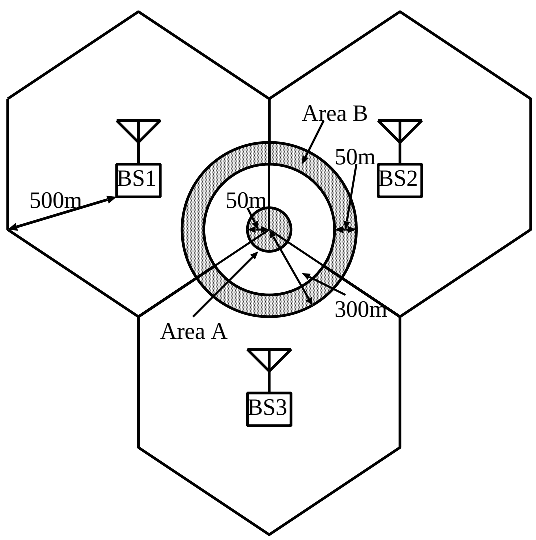

Figure 10: The location of area A and B.

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