Evaluation of Information Transmission with Parallel Pilot Signal for Multipath Estimation Based on Kronecker Product with DFT

Toshiaki IMOTO
Soka University
Department of Information Systems Science
1-236 Tangi, Hachioji, Tokyo 192-8577
Japan

Naoki SUEHIRO
University of Tsukuba
Graduate School of Science and Engineering
Tsukuba, Ibaraki
Japan

Abstract: The authors have been proposed a method of very efficient wireless frequency usage. It is based on the measurement of multipath property for each timeslot, and the coherent addition of multipath signals. The method has been implemented an LSI chip. However, the quantitative analysis is remained. In this paper, we prove the effectiveness of this multipath estimation method under the multipath environment quantitatively using by simulation model.

Key–Words: 4G mobile communication, sequence design, ZCZ-CDMA, wireless frequency usage efficiency, high-rate wireless communication

1 Introduction

We have proposed a very efficient frequency usage system based on multipath estimation and spread time signals based on the signal design of zero correlation zone (ZCZ) signals using complete complementary codes. [1][2][6]. The method has been implemented as a baseband LSI chip[4].

And we have proposed other new zero cross-correlation zone (ZCCZ) signals based on periodic sequence set without crosscorrelation[3] is applied on the method of reference[1] [2]. The system uses the pilot signal for measurering the multipath properties by time shift delay as the complex value. The pilot signal and the data transmission signals can be used independently in the same time and the same frequency band without crosscorrelation nor interference. The system can get the current multipath properties and use them to detect the transmitted data by adding the multipath signals coherently.

And we have proposed a method to make sparse ZCCZ signals[5], so that the transmitted signal doesn't have the problem of amplifier dynamic range.

In this paper, we prove the effectiveness of this multipath estimation method[5] under the multipath environment quantitatively using by simulation model.

2 Information Theoretical View Point

In information theory, the channel capacity is defined based on the S/N ratio. However, what is the noise power? Usually, unuseful multipath signal energy is regarded as noise energy. But when we can estimate all of the multipath time delay, all of the multipath energy can be used by gathering the energy coherently. In fact, the amplitude and the phase for each time slot is enough to use the multipath signal energy as useful signal energy. In this case, the signal power is increased and the noise power is decreased, so the channel capacity is increased.

In current mobile communication technology, only several large power multipath signals are regarded as useful multipath signals, and other multipath signals are regarded as noise, and sometimes the estimation of the large multipath signal is difficult by many reason. On the other hand, our method can almost always estimate the multipath properties of each time slot, and increase the channel capacity significantly.

The remained problem was that the dynamic range of transmitter amplifier is sometimes not enough. So, we have proposed the new method[5] that sparse signals can also be used, and have enough property of very efficient wireless frequency usage.

3 Sequence Set without Periodic Crosscorrelation

In this section, we review the new method to make sequence sets without periodic crosscorrelation[3].

Let F_N be the N-point DFT matrix as:

$$\begin{aligned}&\sqrt{N}F_N\\ =&\begin{bmatrix} W_N^0 & W_N^0 & \dots & W_N^0 \\ W_N^0 & W_N^{-1} & \dots & W_N^{-(N-1)} \\ : & : & & : \\ W_N^0 & W_N^{-(N-1)} & \dots & W_N^{-(N-1)(N-1)} \end{bmatrix}\\ =&\sqrt{N}\begin{bmatrix} f_0 \\ f_1 \\ : \\ f_{N-1}\end{bmatrix},\end{aligned}$$

where $W_N = \exp\left(\frac{2\pi j}{N}\right)$.

Let X and Y also be $X = (x_0, x_1, \dots, x_{L-1})$ and $Y = (y_0, y_1, \dots, y_{L-1})$. Then, we can obtain $\sqrt{N}f_k \otimes X$ and $\sqrt{N}f_l \otimes Y$ as:

$$\begin{aligned}&\sqrt{N}f_k \otimes X\\ =&(W_N^0 x_0, \dots, W_N^0 x_{L-1}\\ &W_N^{-k} x_0, \dots, W_N^{-k} x_{L-1}\\ &:\\ &W_N^{-k(N-1)} x_0, \dots, W_N^{-k(N-1)} x_{L-1}),\end{aligned}$$

$$\begin{aligned}&\sqrt{N}f_l \otimes Y\\ =&(W_N^0 y_0, \dots, W_N^0 y_{L-1}\\ &W_N^{-l} y_0, \dots, W_N^{-l} y_{L-1}\\ &:\\ &W_N^{-l(N-1)} y_0, \dots, W_N^{-l(N-1)} y_{L-1}),\end{aligned}$$

where $\otimes$ is the Kronecker product.

The length of each of $\sqrt{N}f_k \otimes X$ and $\sqrt{N}f_l \otimes Y$ is NL. When we investigate $F_{NL}(\sqrt{N}f_k \otimes X)$, we know that the spectrum has non-zero terms only at the $k(\text{mod}N)$'th terms. So, it is obvious that when $k \neq l$, the periodic crosscorrelation function between $\sqrt{N}f_k \otimes X$ and $\sqrt{N}f_l \otimes Y$ is zero at every term.

4 Very Efficient Usage of Wireless Frequency

In this section we propose a new method to use the wireless frequency very efficiently. The method is based on a method to measure the multipath properties and a method to use multipath signals by the coherent addition using a linear equation.

The method is explained by using a small example.

Let $\{A, B, C, D\}$ be a set of periodic sequence, where

$$\begin{aligned} A &= (\ 1,\ 1,\ 1,\ 1\ ) \\ &\quad\otimes(\ 1,\ 1,\ 1,\ -1) \\ B &= (\ 1,\ j,\ -1,\ -j\ ) \\ &\quad\otimes(\ 1,\ 0,\ 0,\ 0) \\ C &= (\ 1,\ -1,\ 1,\ -1\ ) \\ &\quad\otimes(\ 1,\ 0,\ 0,\ 0) \\ D &= (\ 1,\ -j,\ -1,\ j\ ) \\ &\quad\otimes(\ 1,\ 0,\ 0,\ 0). \end{aligned} \tag{1}$$

4.1 measurement of Multipath Properties

In this example, we define 'a multipath vector' $P = (p_0 p_1 p_2 p_3)$, where each of p_0, p_1, p_2 and p_3 denotes the complex multipath factor of each time slot, so each of $p_0 \dots p_3$ is a complex number. Note that p_0 denotes the direct path, so we can suppose $p_0 = 1$.

We can see from the formula (1)

$$\begin{aligned} A = (&\ 1,\ 1,\ 1, -1,\ 1,\ 1,\ 1, -1, \\ &\ 1,\ 1,\ 1, -1,\ 1,\ 1,\ 1, -1\ ). \end{aligned}$$

Let A' be a finite length pseudoo-periodic sequence of pseudo-period 16.

$$A' = (\ 1,\ 1,\ 1, -1,\ A,\ 1,\ 1,\ 1, -1\ ).$$

The length of A' is $4 + 16 + 4 = 24$. We can regard A' is obtained by cutting a sequence of length 24 from the infinite length sequence $(\dots AAAA \dots)$.

In this example, we use another pseudo-periodic signal $(A', 1)$ of length 25, so that the length of the signal is exactly fittable to the method.

When we input the signal $(A', 1)$ into the matched filter for A, we obtain the output signal

$$\begin{aligned} (A', 1) * \overline{A} = &\ 16(x, x, \dots, x, x, 1, 0, 0, 0, \\ &\ 1, 0, 0, 0, 1, 0, x, x, \dots, x, x), \end{aligned} \tag{2}$$

where each x denotes some value.

Because the multipath property is $P = (p_0, p_1, p_2, p_3)$, the receiver should receive the signal

$$\begin{aligned} A'' = &\ p_0(A', 1, 0, 0, 0) \\ &+ p_1(0, A', 1, 0, 0) \\ &+ p_2(0, 0, A', 1, 0) \\ &+ p_3(0, 0, 0, A', 1). \end{aligned} \tag{3}$$

When this received signal is input to the matched filter for A, the filter outputs:

$$\begin{aligned} &A'' * \overline{A} \\ =&\ 16(x, x, x, \dots, x, x, x, \\ &p_3, p_0, p_1, p_2, p_3, p_0, p_1 \\ &x, x, x, x, \dots, x, x). \end{aligned} \tag{4}$$

So, when transmit the signal $(A', 1)$ under the multipath environment of $P = (p_0, p_1, p_2, p_3)$, and receive the signal by the matched filter for A, we can obtain the multipath property (p_0, p_1, p_2, p_3) as the output of the filter matched for A.

Figure 1 shows conceptual figure of equation (2) and of equation (4) .

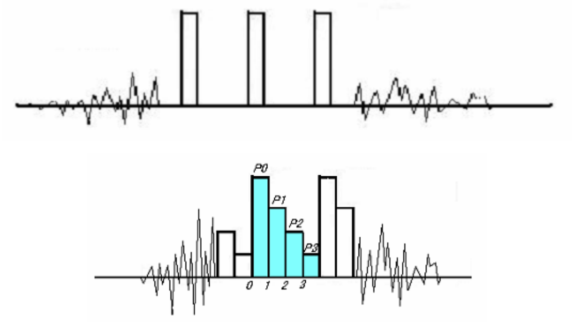

Figure 1: Filter out put under no multipath and under multipath environment.

4.2 Signal for Information Transmission

From the formulae (1), we can also see

$$\begin{aligned} B \; = \; & (\, 1,\ 0,\ 0,\ 0,\ j,\ 0,\ 0,\ 0, \\ & -1,\ 0,\ 0,\ 0, -j,\ 0,\ 0,\ 0\,). \end{aligned}$$

Let B' also be a finite length pseudo-periodic sequence of pseudo-period 16:

$$B' = (-j,\ 0,\ 0,\ 0,\ B,\ 1,\ 0,\ 0,\ 0\,).$$

The length of B' is 4 + 16 + 4 = 24. We can regard B' is also obtained by cutting a sequence of length 24 from the infinite sequence $(\ldots BBBB \ldots)$.

When we input the pseudo-periodic signal (B', j) of length 25 and pseudo-period 16 into the matched filter for A, we obtain the output signal

$$\begin{aligned} (B', j) * \overline{A} \; = \; & (x, x, \ldots, x, x, 0, 0, 0, 0, 0, \\ & 0, 0, 0, 0, 0, x, x, \ldots, x, x). \end{aligned}$$

When we input the signal $(A', 1)$ of length 25 into the matched filter for B, we obtain the output signal

$$\begin{aligned} (A', 1) * \overline{B} \; = \; & (x, x, \ldots, x, x, 0, 0, 0, 0, 0, \\ & 0, 0, 0, 0, 0, x, x, \ldots, x, x). \end{aligned}$$

So, the signals $(A', 1)$ and (B', j) can be used independently at the simultaneous.

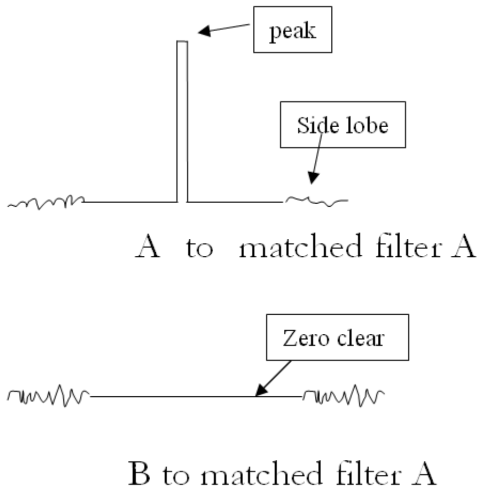

Figure 2: Conceptual figure of the filter out put between different sequence.

Figure 2 shows the different output with ZCZ(zero correration zone) in different sequence input.

Now, we should consider the multipath environment.

When the signal (B', j) is transmitted under the multipath environment P, the receiver receives the signal:

$$\begin{aligned} B'' \; = \; & p_0(B', j, 0, 0, 0) \\ & + p_1(0, B', j, 0, 0) \\ & + p_2(0, 0, B', j, 0) \\ & + p_3(0, 0, 0, B', j). \end{aligned} \tag{5}$$

When the received signal A'' of the formula (3) is input to the matched filter for B, the output signal is:

$$\begin{aligned} A'' * \overline{B} \; = \; & (x, x, \ldots, x, x, 0, 0, 0, \\ & 0, 0, 0, 0, x, x, \ldots, x, x). \end{aligned}$$

Similarly, when the received signal B'' of the formula (5) is input to the matched filter for A, the output signal is:

$$\begin{aligned} B'' * \overline{A} \; = \; & (x, x, \ldots, x, x, 0, 0, 0, \\ & 0, 0, 0, 0, x, x, \ldots, x, x). \end{aligned}$$

So, the pseudo-periodic signals $(A', 1)$ and (B', j) can be used independently without crosscorrelation even under the multipath environment P. Thus, we can use $(A', 1)$ as a pilot signal to measure the multipath property and use (B', j) as an information transmission signal.

When (B', j) is input to the matched filter for B, the output signal is:

$$\begin{aligned}(B', j) * \overline{B} \;\; = \;\; & (x, \ldots, x, -4j,\ 0, \\ & 0,\ 0, 4,\ 0, \\ & 0,\ 0, 4j,\ 0, \\ & 0,\ 0, -4, x, \ldots, x).\end{aligned}$$

So, when the received signal of the formula (5) is input to the matched filter for B, the output signal is:

$$\begin{array}{cc} & B'' * \overline{B} \\ = & 4(\ldots,\ x,\ x,\ x,\ x, \\ & -jp_0, -jp_1, -jp_2, -jp_3, \\ & p_0, p_1, p_2, p_3, \\ & jp_0, jp_1, jp_2, jp_3, \\ & x,\ x,\ x, \ldots).\end{array} \quad (6)$$

4.3 Information Transmission Method

When the multipath problem is solved, the signals $(B', j, 0)$ and $(0, B', j)$ are recognized as the different signals. So, both signals can carry the different data.

In this example, the data $(b_0, b_1, b_2, b_3, b_4, b_5)$ is carried by the chip-shifted signals $(B', j, 0, 0, 0, 0, 0)$, $(0, B', j, 0, 0, 0, 0)$, $(0, 0, B', j, 0, 0, 0)$, ..., and

$(0, 0, 0, 0, 0, B', j)$.

So, the transmitted signal should be:

$$\begin{array}{c} b_0(B', j, 0, 0, 0, 0, 0) \\ +b_1(0, B', j, 0, 0, 0, 0) \\ +b_2(0, 0, B', j, 0, 0, 0) \\ \cdots \\ +b_5(0, 0, 0, 0, 0, B', j). \end{array} \quad (7)$$

When this signal is transmitted under the multipath environment P, and the received signal is input to the matched filter for B, the output signal is:

$$\begin{array}{l}(x, x, \ldots, x, x, \\ q_0, q_1, q_2, q_3, q_4, q_5, q_6, \\ x, x, \ldots, x, x),\end{array}$$

where

$$\frac{1}{4}\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_6 \end{bmatrix} = \begin{bmatrix} p_1 & p_0 & -jp_3 & -jp_2 & -jp_1 & -jp_0 \\ p_2 & p_1 & p_0 & -jp_3 & -jp_2 & -jp_1 \\ p_3 & p_2 & p_1 & p_0 & -jp_3 & -jp_2 \\ jp_0 & p_3 & p_2 & p_1 & p_0 & -jp_3 \\ jp_1 & jp_0 & p_3 & p_2 & p_1 & p_0 \\ jp_2 & jp_1 & jp_0 & p_3 & p_2 & p_1 \\ jp_3 & jp_2 & jp_1 & jp_0 & p_3 & p_2 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix}.$$

Thus, we got a system of 7 linear equations in 6 unknowns, where $b_0, b_1, b_2, \ldots$ and b_5 are unknowns. Because p_0, p_1, p_2 andp_3 are obtained as the output of the matched filter for A, and $q_0, q_1, q_2, \ldots$ and q_6 are obtained as the output of the filter, the linear equation system can be solved easily. So, the transmitted data $(b_0, b_1, b_2, b_3, b_4, b_5)$ are detected even under the multipath environment P.

If we can use the complex number sequences, we can use large scale DFT matrices. So, in future, this method will give us very efficient wireless communication method. Note that if we use wider frequency band, the time slot should be narrower, and the resolution of multipath become better. The resolution of multipath means the addition of plural multipath signals is divided into plural signals.

5 Simulations

5.1 Scheme of the transmission system using kronecker product with DFT for simulation

We employed here 8-point DFT matrix. As we mentioned in previous section 3, we can apply this method to any length of data. So, we determine the length of data is 89 in this simulation. So, the chip length is $8 \times 89 = 712$. Then we add 64 chips both edge of these chips for making pseudo-periodic signal. So, the total chip length is 840. As we mentioned previous sections, there are 8 orthogonal sequences in the case of 8-point DFT matrix. One of 8 DFT rows is using as a pilot signal, so we put the orthogonal sequences as a data in order to make a clear main pulse with matched filter. Then we can get a code gain for pilot signal. Another 7 sequences of DFT rows are using for the data transmission, so we can transmit 7×89 data at the same time. These each data can be complex number, so we applied 64QAM for each data. So, the total transmitted information are $7 \times 89 \times 6 = 3738$ bits. The transmission rate is $3738/840 = 4.45$ bits/chip.

I'd like to point up again, the pilot signal and the data signals are sent simultaneously. So, the multipath effect is the same between the pilot and the data signals. It means that the accuracy of multipath estimation is very good in the time axis.

5.2 The structure of transmitter and receiver model

The structure of transmitter and receiver model is as Figure 3. This simulation is based on the equivalent low-pass system model. In order to this, each chips are composed by 4 samples. Band width is limited by the root nyquist filter. We assumed the sampling for receiver is exactly fit to chip synchronization.

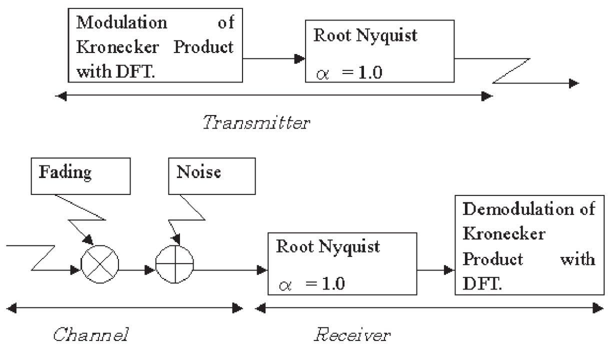

Figure 3: Transmitter and receiver model.

5.3 Effectiveness of the multimath estimation method

There are some assumptions for the fading environment. Receiver dose not move so quickly. Chip rate is 1μ sec,1 MHz. The carrier frequency band is 1 GHz. For the relative power of relative delay time to main pulse, the carrier delay profile is assumed as COST207(monotony droped by 30 dB in 7 μ sec delay). Carrier for each time slot is reached as a rayleigh fading. As a result of the fading with this delay profile, the multipath fading power is 43 % of original total signals power.

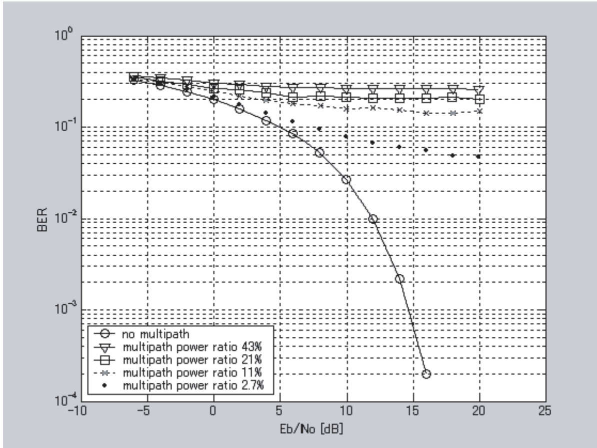

Figure 4: BER for 64QAM without multipath estimation under the multipath environment.

Figure 4 shows the bit error rate with a parameter of the controlled multipath fading power as 1/2, 1/4 from the original profile. According to this Figure 4, the bit error rate for ordinary 64QAM without multipath estimation is very bad even in a small power of fading environment. Figure 5 shows the bit error rate of the dft-kronecker product system with multipath estimation under the multipath environment. According to Figure 5, the bit error rate for dft-kronecker product system with multipath estimation is very good as compared with 64QAM without multipath estimation.

Figure 6 is combined of Figure 4 & 5 in order to easy comparison between these two systems. When no fading, the dft-kronecker product system with multipath estimation seems to be slightly bad compare with 64QAM. That is cause to the accuracy of a pilot signal estimation. If there was not the estimation error, this bit error rate line assumed to be just fit to the line of 64QAM. On the other hand, the dft-kronecker product system with multipath estimation has a good property under the fading environment.

6 Conclusion

we proved the effectiveness of this multipath property estimation method quantitatively using the dft-kronecker product system under the heavy multipath environment.

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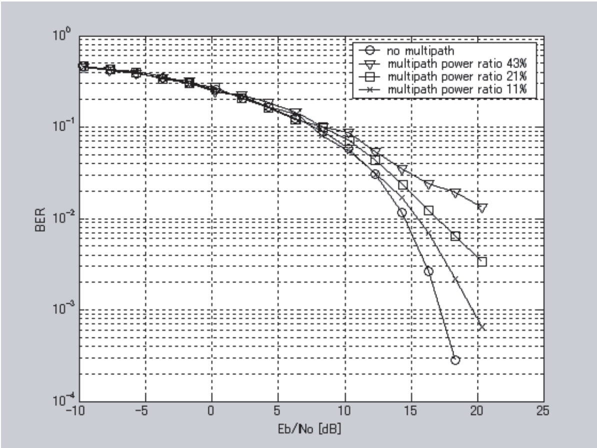

Figure 5: BER for dft-kronecker product system with multipath estimation under the multipath environment

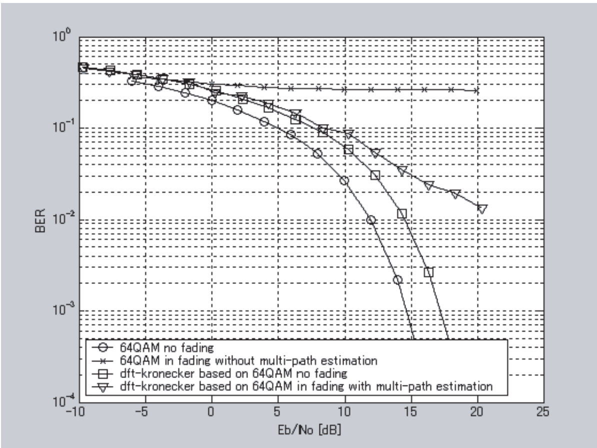

Figure 6: Comparison between ordinary 64QAM without multipath estimation and dft-kronecker system with multipath estimation.

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