A Constant Amplitude Multiplexing for Multi-Code DS/CDMA Systems

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***Abstract*—In general, the signal of the conventional multi-code CDMA system has large fluctuations, and these fluctuations increase nonlinear distortion at a high efficient nonlinear amplifier. To reduce nonlinear distortion, the amplitude fluctuations of the signal should be reduced as much as possible, so majority multiplexing and constant amplitude coding are developed. But, as the system uses more codes, both methods make the system more complex, because the data bits are coded several times. The proposed system does not need the additional coding and just needs simple sign operations. And it uses the same simple receiver as the conventional multi-code system.**

I. Introduction

One of the mobile communication systems, code division multiple access (CDMA) is a very attractive system and has been focused on as the third-generation (3G) system. The 3G system requires high data rate, high QoS, large capacity, and flexibility. The most important feature of the 3G system is to service very high data rate of maximum 2 Mbps. This system can offer a variable data rate service using multi-code for high rate and a variable spreading gain method for low rate.

Especially, the multi-code CDMA system can offer a higher service rate than any other system, and has enough ability to transfer a MPEG2 video stream. But, it has a problem of large amplitude fluctuations from multiplexing several codes. These fluctuations cause nonlinear distortion and out-of-band radiation at a nonlinear amplifier [1]. To reduce nonlinear distortion, the amplitude fluctuations of the signal should be reduced as much as possible. These fluctuations can be described as the parameter, peak-to-average power ratio (PAPR).

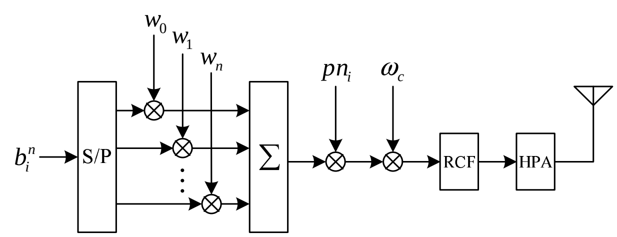
As the methods of removing fluctuations, majority multiplexing and constant amplitude coding are developed [2], [3]. These methods make the amplitude of the signal constant using redundant power for constant enveloping. But, if the system uses many codes, both methods should be used as a 2-fold or more and it will make the system much complicated, because the data bits should be coded two times or more.

In this paper, a simple system using majority multiplexing is proposed for the reduction of PAPR. First, the behavior of the conventional multi-code CDMA system and the majority multiplexing CDMA system will be shown. Then our proposed system will be introduced. Finally, the performance of the proposed and conventional systems will be compared.

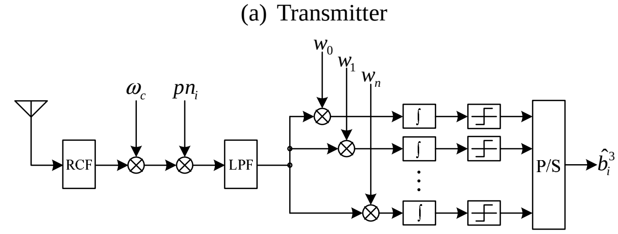
II. System Model

A. Conventional Multi-Code CDMA System

The block diagram of the conventional multi-code CDMA system is given in Figure 1.



(a) Transmitter



(b) Receiver

Fig. 1. Conventional multicode CDMA system

At the transmitter, the original data stream of a user is represented as

$$b(t) = \sum_{k=-\infty}^{+\infty} b_k \cdot p_T(t - kT) \tag{1}$$

where $p_T(t) = 1\ (0 \leq t \leq T)$, $p_T(t) = 0\ (otherwise)$, and T is the bit duration.

This data stream is divided into N parallel sub-streams by a serial-to-parallel converter. The number of sub-streams is determined by the required service rate. The original data stream before the S/P conversion can be expressed as

$$b(t) = \sum_{i=-\infty}^{+\infty} \sum_{n=1}^{N} b_i^n \cdot p_T(t - (iN + n)T) \quad (2)$$

And, the n-th sub-stream is as

$$b^n(t) = \sum_{i=-\infty}^{+\infty} b_i^n(t - iNT) = \sum_{i=-\infty}^{+\infty} \frac{1}{\sqrt{N}} \cdot b_i^n \cdot p_{NT}(t - iNT) \quad (3)$$

where $p_{NT}(t) = 1\ (0 \le t \le T)$, $p_{NT}(t) = 0\ (otherwise)$.

Then, n-th sub-stream multiplied by each WH sequence is as

$$b_w^n(t) = \sum_{i=-\infty}^{+\infty} \sum_{j=1}^{N_w} \frac{1}{\sqrt{N}} \cdot b_i^n \cdot w_j^n \cdot p_{T_w}(t - (iN_w + j)T_w) \quad (4)$$

where $N_w T_w = NT$.

The summed signal is

$$b_w^n(t) = \sum_{n=1}^{N} \sum_{i=-\infty}^{+\infty} \sum_{j=1}^{N_w} \frac{1}{\sqrt{N}} \cdot b_i^n \cdot w_j^n \cdot p_{T_w}(t-(iN_w+j)T_w) \quad (5)$$

Consequently, the amplitude of the summed signal has lots of peaks and large fluctuations. This signal is then multiplied by the Pseudo-Noise (PN) sequence assigned to each user as

$$\begin{aligned} b_s(t) &= \sum_{n=1}^{N} \sum_{i=-\infty}^{+\infty} \sum_{j=1}^{N_w} \sum_{l=1}^{T_w/T_c} \frac{1}{\sqrt{N}} \cdot b_i^n \cdot w_j^n \cdot pn_{j \cdot T_w/T_c} \\ &\quad \cdot p_{T_c}(t - (iN_w + j)T_w - lT_c) \end{aligned} \quad (6)$$

where $N_w T_w = N_c T_c$ $(N_w \le N_c)$. And the PAPR of this summed signal is

$$PAPR = \frac{max|b_s^2|}{E[b_s^2]} = \frac{N^2}{N} = N \quad (7)$$

Then, the Raised-Cosine Filter (RCF) for pulse shaping filters the signal as

$$s(t) = b_s(t) * \Big(\frac{cos(\pi\beta t/T_c)}{1 - (2\beta t/T_c)^2} \cdot sinc(\frac{t}{T_c}) \Big) \quad (8)$$

where β is the roll-off factor.

After the modulation, the signal is as

$$s_{mod}(t) = |s(t)| \cdot cos\Big(\omega t + \psi(t)\Big) \quad (9)$$

where $\psi(t) = arg\big(s(t)\big)$. And, the PAPR of the modulated signal increases by about 3dB.

After that, a power amplifier (PA) amplifies the amplitude of the signal to the desired power level and the output signal of the PA passes channel.

At the receiver, the received signal is filtered by the BPF. The filtered signal is demodulated and multiplied by the pseudo-noise sequence again. After filtered by a Low Pass Filter (LPF), the signal is multiplied by each WH sequence and integrated for decision. Finally, these estimated data streams are converted to one data stream.

B. Majority Multiplexing CDMA System

Majority multiplexing CDMA system is described in Figure 2. The process of transmission is the same as the conventional system except an additional process. In the transmitter, after the parallel signals are summed, only the sign of the signal is captured and multiplied by the PN sequence. The structure of the receiver is the same as the conventional system. Because the summed signal is change to a constant amplitude signal, the correlation values at the receiver are also changed.

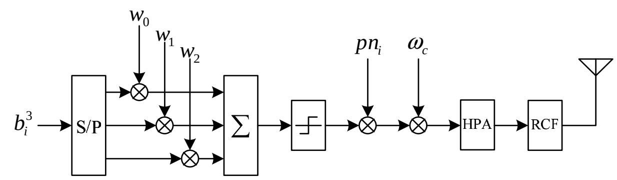
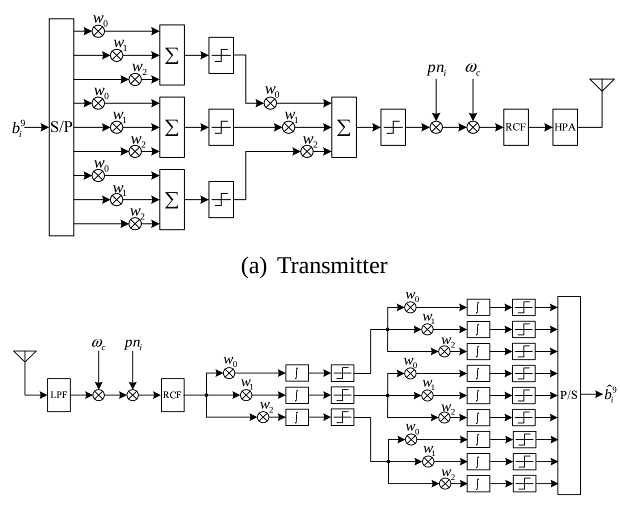


Fig. 2. Transmitter using majority multiplexing method with 3 channels

Majority multiplexing method can be used in 3-code and 7-code CDMA systems [1]. If this multiplexing is done several times as 2 or more-fold system, the system can use $3^n \times 7^m$ codes simultaneously. The 2-fold 9-code majority multiplexing system is shown in Figure 3.



(a) Transmitter

(b) Receiver

Fig. 3. 2-fold majority multiplexing symtem using 9 codes

When the system uses 3^n perfect WH codes as the current IS-95 CDMA system, all the correlation values are degraded to the same value in the comparison of the conventional system. PN sequences also can be chosen as imperfect orthogonal codes [2], [4]. If the system uses imperfect orthogonal codes as m-sequences, truncated WH codes or 7^m perfect WH code, the reassurance values change very deeply depending on data bits and codes. In most cases, the receiver receives lower correlation value then the perfect 3^n code system at the same transmission power, so the performance is even lower than the perfect code system.

If the system uses a linear amplifier, the performance of the system is lower than that of the conventional system due to the power redundancy. But, when using a nonlinear amplifier, the constant amplitude signal of the perfect code system shows better performance than the signal of the conventional system, which has large fluctuations.

C. Constant Amplitude Coding CDMA System

The constant amplitude coding CDMA system is first developed by Tadahiro [3]. The basic method is the same as the 3^n-code majority multiplexing except that this method uses another specific code to make the signal constant instead of capturing the sign of the summed signal. The 3-channel transmitter is shown in Figure 4.

This method can be used not only in the 4-by-4 WH sequences but also in any length 4^n WH sequences. The total set of WH sequences having any length has specific combinations of constant amplitude coding. These combinations are based on the constant amplitude coding of basic 4-by-4 WH-code block. If the system choose specific 3 codes from WH codes set of any length, there is another code making constant amplitude.

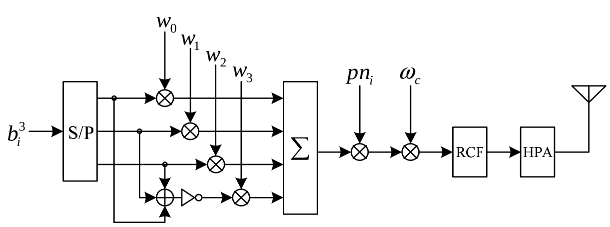


Fig. 4. Transmitter using constant amplitude coding method with 3 channels

At the transmitter, the system makes one redundant bit using 3 other data bit for constant amplitude coding. Especially when using 4-by-4 WH sequences, specific combinations of 4 bits make constant envelope. (The number of those combinations is exactly a half of the number of total possible combinations.) Therefore, the system makes one redundant bit using 3 other original data bits in the 3-code model. After that, each substream is multiplied by each WH sequences and summed to one signal.

Actually 3-code model of the constant amplitude coding is the same as 3-code majority multiplexing model. These two models waste about 25% of the total power as the redundant bit for every coding, but it can be used for parity checking in the constant amplitude coding. In the case of a 7-code majority-multiplexing model, about 30% of the total power are redundant for every constant enveloping, and it can also be used for parity checking.

If we use 2-fold constant amplitude coding of 9-code, there are 7 redundant sub-streams of the total 16 sub-streams. In this case, about a half, exactly 44% of the total power are redundant. But, the redundant bits have an ability of correcting one error bit as well as error detection [5].

D. Proposed System

A WH code set of order $N = 2^n$ has 2^n codes, denoted $\{W_0, W_1, \cdots, W_{2^n-1}\}$. In the proposed system, the set of the first coding blocks consists of every sequent 4 codes from W_0 to W_{2^n-1}; $\{W_0, W_1, W_2, W_3\}$, $\cdots$, and $\{W_{2^n-4}, W_{2^n-3}, W_{2^n-2}, W_{2^n-1}\}$. The set of second coding blocks consists of every sequent 16 codes; $\{W_0, \cdots, W_{15}\}$, $\cdots$, and $\{W_{2^n-16}, \cdots, W_{2^n-1}\}$, in which each second coding block has 4 first coding block. So, the set of k-th coding blocks consists of every sequent 4^k codes, and each k-th coding block has 4 $(k-1)$th coding blocks.

The proposed multiplexing comprises several majority-multiplexing levels. The first level multiplexing is executed in the level of the first coding, in which arbitrary 3 codes of the total 4 codes are used for multiplexing. The second level multiplexing is also executed in the level of the second coding, in which arbitrary 3 codes of the total 4 codes of the first coding output. So, in the k-th level multiplexing, arbitrary 3 codes of the total 4 codes of the $(k-1)$th coding output. As a result, the system uses 3^n codes and spends the power of 4^n codes, *i.e.* the power of $4^n - 3^n$ codes are redundancy. The selection of WH codes in the proposed 27-code system of 64 chips is shown as an example in Figure 5.

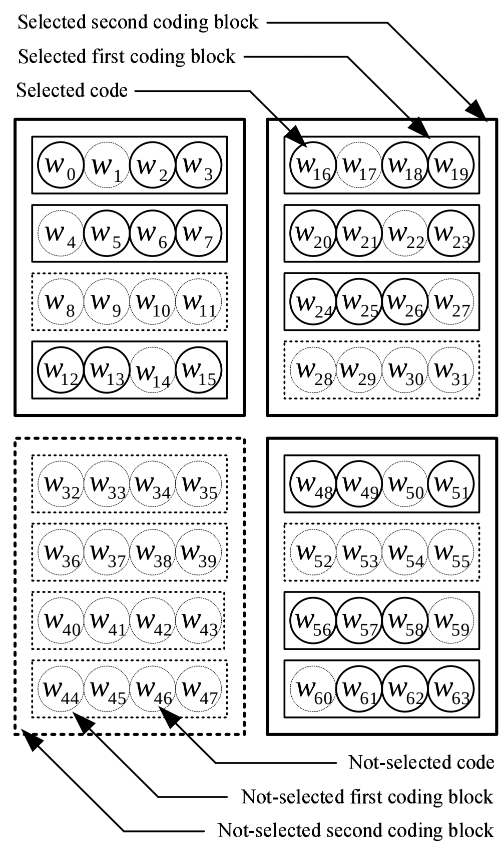
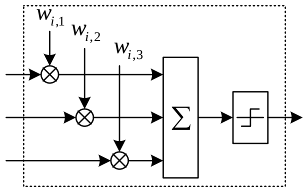
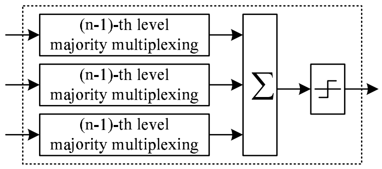


Fig. 5. Selection of codes in the proposed 27-code system of 64 chips

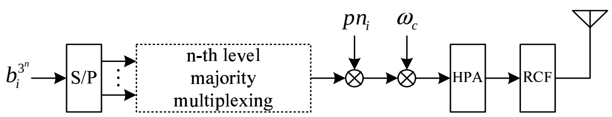
Basically, the proposed system makes the output of multiplexing of 3^n codes have constant amplitude as Figure 6. If the



(a) First level majority multiplexing of 3 codes



(b) n-th level majority multiplexing



(c) Transmitter of the proposed system

Fig. 6. Constant amplitude multiplexing system

system does not need exactly 3^n codes, the proposed method can be used to reduce PAPR of the signal by not majority multiplexing at the last level. The receiver structure of the proposed system is the same as the conventional multicode system.

This system has the same redundancy power in the proportion of the number of majority-multiplexing levels. Because the amount of redundancy is the same as majority multiplexing and constant amplitude coding, the performance of the system is also same. The main difference between the proposed and these systems is the number of coding and chips.

When using majority multiplexing and constant amplitude coding, the number of total chips is

$$N_{chips,total} = (N_{chips,coding})^{N_{coding}} \tag{10}$$

where $N_{chips,totoal}$ is the number of chips for each coding, and N_{coding} is the number of codings. So, this number of total chips is limited to one of specific numbers. But, the proposed system does not need additional coding, the number of total chips that the system needs can be applied directly. If a mobile needs 9 codes, majority multiplexing and constant amplitude coding methods increase the number of the total orthogonal modulation chips to the square of the number of chips of each coding, and the complexity also increases.

E. High Power Amplifier (HPA)

The HPA can be viewed as a nonlinear filter with gain and phase characteristics. The power efficiency of an amplifier is mainly determined by Peak-to-Average Power Ratio (PAPR).

PAPR determines the degree of nonlinear distortion and power loss by out-of-band radiation. All HPAs have a specific input point making saturation output power level, so they should limit power level of input signal. A parameter called "backoff" means the ratio of average and peak power. We used output backoff (OBO) instead of PAPR in this model. If we use a model using more channels, the PAPR of the model is also increased in proportion to the increased number of using channels.

In a HPA, high OBO level decreases nonlinear distortion and preserves original shape of each pulse. In addition, it is related to power efficiency of the HPA, *i.e.* the OBO level increase means not only improvement of BER but also degradation of power efficiency and it needs more capacity of a HPA.

HPA models are generally divided into Traveling-Wave Tube Amplifier (TWTA) and Solid-State Power Amplifier (SSPA) models. We chose TWTA as a high efficient HPA according to the Saleh model [7].

The input signal to TWTA is described as

$$x(t) = r(t) \cdot cos\Big(\omega_c t + \psi(t)\Big) \tag{11}$$

where $r(t)$ and $\psi(t)$ are the amplitude and phase of the input signal respectively, and ω_c is the carrier frequency. The output signal can be written as

$$y(t) = A[r(t)] \cdot cos\Big(\omega_c t + \psi(t) + \Phi[r(t)]\Big) \tag{12}$$

Then, the amplitude (AM-AM) and phase (AM-PM) characteristic of TWTA is described as

$$A(r) = \frac{\alpha_a r}{1+\beta_a r^2} \quad and \quad \Phi(r) = \frac{\alpha_\phi r^2}{1+\beta_\phi r^2} \tag{13}$$

where the parameters α_a, β_a, α_ϕ, and β_ϕ are dependent of the type of TWTA model.

III. Simulation

The simulation has been carried out under the additive white Gaussian noise and the ideal synchronization. We measured the bit error rate (BER) performance of conventional and the proposed method.

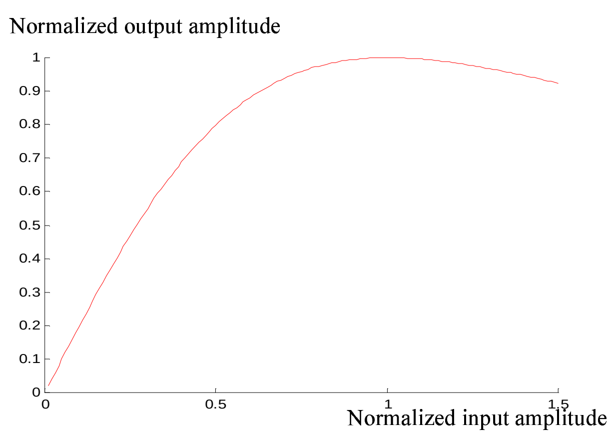
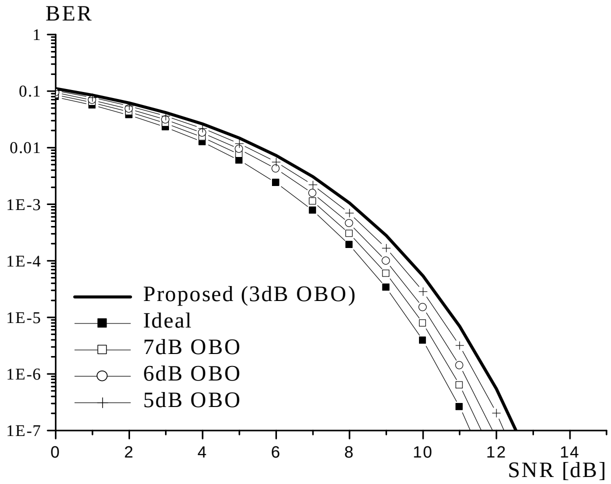
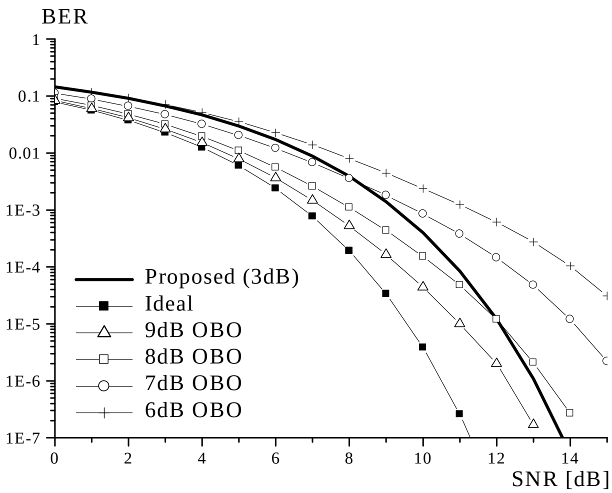


Fig. 7. TWTA amplitude characteristic



(a) Proposed and conventional 3-code systems



(b) Proposed and conventional 9-code systems

Fig. 8. BER performance of the proposed and conventional systems

Both of an ideal linear amplifier and a HPA are used for comparison. TWTA was chose as an HPA, and we simulated each case of several OBO level cases. As the optimum normalized parameters α_a and β_a, 1.9638 and 0.9945 is selected from data reference [8]. In general, the effect of the phase characteristic is relatively small, so only the phase characteristic is ignored. The amplitude characteristic of the selected parameters is shown in Figure 7.

Figure 8(a) shows the BER performances of an ideal linear amplifier and a HPA in the conventional and proposed 3-code system. The BER performance of majority multiplexing and constant amplitude coding was the same as that of the proposed method, so we did not show it. In the proposed 3-code system, the use of a HPA as 3dB OBO is the same as majority multiplexing. So, the proposed method is not effective in the 3 codes.

Figure 8(b) shows the 9-code case, which explains the trade-off relationship of the OBO level (the power efficiency and the size of the HPA) and the BER performance at the conventional system. In the figure, the performance of the proposed system of 3dB OBO is similar to the 6dB case of the conventional system at low SNR, and the performance is better as SNR increases.

When a linear amplifier with 3dB OBO was used, the proposed system had some BER degradation the same as majority multiplexing and constant amplitude coding system. It is because those systems lose much portion of power as the additive redundant sub-stream. But, the degradation of the proposed system with 3dB OBO reduction is much smaller than that of the conventional system.

IV. Conclusions

A conventional multi-code transmission has large PAPR, which induces large nonlinear distortion and power loss from out-of-band radiation. So the constant enveloping methods as majority multiplexing and constant amplitude coding are developed and they make multi-code transmission using an HPA more efficient. But, the complexity of those systems increases in the proportion of the number of codings and the structure of the receiver should also be changed. And the number of total chips is limited to one of specific numbers

The proposed system using more than 3 codes shows the same performance of the above two systems, but its coding process is more simple and the structure of the receiver is the same as the conventional system. The number of total chips is not limited, and can be chosen at any length. This method can also be used at base stations for reducing the capacity and PAPR of a HPA.

References

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