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Application of Virtual Segment Interleaving to High Speed Land Mobile Communication System and Transmission Characteristics of the Low Chip Rate diffCDMA over Multi-Ray Rayleigh Fading Channel

仮想セグメントインターリービングの高速陸上移動通信システムへの適用と低チップレート diffCDMA のマルチレイレイレーフェーデング伝送特性

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Abstract: As well known, CDMA possesses such advantages as high capacity, low power transmission, and system flexibility, but it is contradictory suffered from broadband occupancy of wasting finite frequency resource owing to innocent spectrum spreading. Narrowing frequency bandwidth occupied over propagation channels is eager to efficiently develop the high capacity digital transmission as one of the most important key technologies promising effective frequency usage.

Narrowing frequency bandwidth both of the primary and secondary modulations has been keenly discussed in these years to realize high capacity and speed diffCDMA. The phase continuity primary DQPSK, which has already reported in VTC98 as the first solution for 2 Mbps/ 8 Mcps diffCDMA, is retrieved here to realize the higher reliability and frequency efficiency 2 Mbps/ 4 Mcps diffCDMA.

Virtual segment interleaving is successfully discussed in this paper to reduce chip rating as one of the important solutions for effective frequency usage without introducing any problem in system reliability and complexity. Both continuous phase primary modulation and continuous chip shaping are also enhanced in this proposing 2Mbps/ 4Mcps diffCDMA.

1. INTRODUCTION

Narrowing frequency bandwidth occupied over propagation channels is eager to efficiently develop the high capacity digital transmission as one of the most important key technologies promising effective frequency usage. Typical IMT2000 CDMA is desired to communicate up to 2 Mbps with using less than 4 Mcps through 4 MHz frequency bandwidth. On the other hand, the narrow frequency band limited signals are easily suffered from BER degradation over poor channels, especially damaged by additional frequency expansion where meg-order high capacity communications from high speed running vehicles.

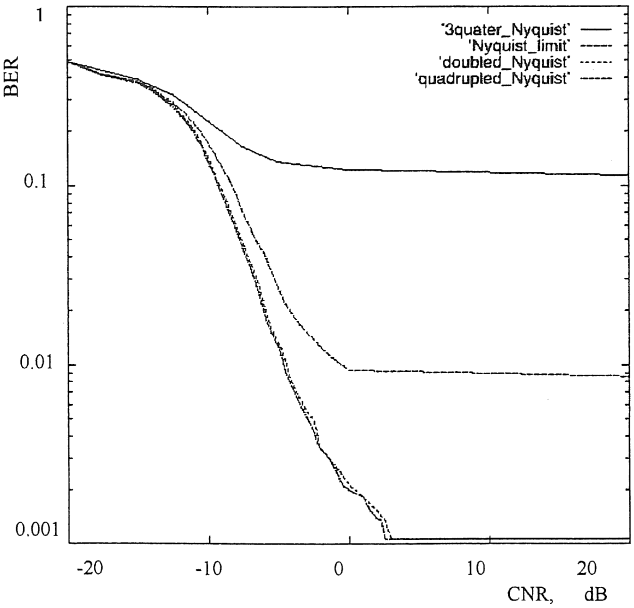

Fig.1 BER vs. CNR of CDMA, limited within Nyquist chip limit, doubled, or quardrupled bandwidth, through two ray Rayleigh fading environment of DUR=10dB with 0.5 micro second delay spread.

As CDMA being as known well given by the direct product of primary modulating PSK and spread spectrum code, the CDMA transmission capacity is nominally defined by the PSK capacity multiplied by the number of spreading spectrum code in the secondary modulation. And the frequency bandwidth of the CDMA is, therefore, defined by the convolution of the PSK and the spread spectrum code bandwidth. Because of the Walsh function being adopted to span the code space in addition to the primary PSK modulation, the CDMA is seemed to inherit robustness from both Walsh code and PSK genius during fading propagation.

BER vs. CNR is shown in fig.1 for 2 Mbps/ 8 Mcps CDMA of employing QPSK as the primary modulation measured after propagation through such two-ray Rayleigh fading environment as 10 dB DUR with 0.5 micro-sec delay spread. As clearly shown in fig.1, the transmission quality is catastrophically degraded if bandwidth being restricted beyond the Nyquist chip limit, i.e. 1 Hz/chip, where it becomes to be remarkable in fading degradation through multi-ray propagation environment. On the other hand, the multi-ray fading robustness is also catastrophically improved in BER meanings by expanding frequency occupancy from the limit to doubled or quadrupled Nyquist chip limit. After expanding the CDMA transmission bandwidth beyond the doubled limit, BER saturates to the characteristics of the doubled limit.

2. HIGH FREQUENCY EFFICIENCY MODULATIONS IN diffCDMA

2.1. Phasese Continuity in the Primary Modulation

Reducing CDMA bandwidth is important for promising efficient frequency usage in realizing such high reliability in narrow bandwidth as free space propagation with base of prevention both from fading bandwidth expansion and spectrum distortion through multi-ray propagation.

PSK phase is illustrated in fig.2. As shown by dotted lines, the existing PSK is given by square topped waves to maintain a unique value over the whole duration of every symbol to cause a jump at every fringe in proportion to the phase difference among the adjacent symbols. If there exists no jump around all fringes, PSK modulated waves are obviously vanished frequency bandwidth to zero with victim of losing transmission ability.

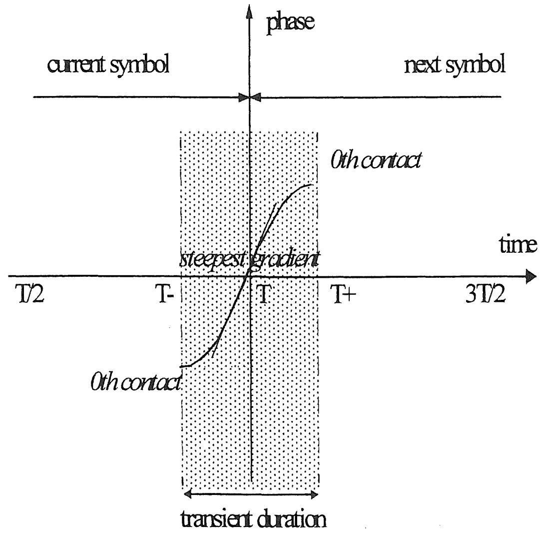

Fig.2 Illustrative time response of continuous phase

It is, therefore, necessary to maintain individual phase value at every symbol center, but is sufficient to keep the same value in neighbors at the center in order to transmit information with phase difference. It becomes to be possible to reduce the occupied bandwidth where the rapid variation is suppressed to yield continuous phase PSK of the primary modulation in CDMA systems.

Phase continuity is facilitated as shown in fig.2 as solid curve by substituting smoothing function in the transient duration spanning over adjacent symbols. The function touches current and next symbol phase values at the front and tail ends with 0th order contact, respectively, and varies with the steepest gradient just at the center of the transient duration, i.e. at the fringe. For example, the following eq.1 is matched to the above phase smoothing function.

$$p(t) = p_c + \Delta_p S(t) \tag{1}$$

Here,

p_c is the current symbol phase value,

$\Delta_p = p_c - p_n$, p_n is the next symbol phase value,

S(t) is such a function given by

$$S(t) = \begin{cases} \frac{1}{2}\left\{1 + \sin\frac{\pi t_m}{\tau}\right\}, & if\ |t_m| \le T \\ 0, & else \end{cases} \tag{2}$$

where,

$$t_m = t\big|_{\mathrm{mod}\,T},\ T\ \mathit{is\ symbol\ duration}. \quad (3)$$

Effect of Phase Continuity

Both lower and upper eight side lobes are shown in fig.3 after averaging instantaneous spectrums over plural symbols. The solid and dotted curves show the comparison between the ensemble spectrum of phase continuous and discontinuous PSK, respectively. When the transient duration is set to a quarter symbol, power levels are suppressed through phase continuity processing by 3.87 and 19.36 dB at the force and eighth harmonics.

It is adequate to assume that all the spectrum except main lobe are interference rather than unnecessary component in communication system, because of the alias being leaked into inside from the outside and of remarkable distortion being occurred at band edges where frequency bandwidth being limited. In paradoxically speaking for phase discontinuous existing PSK and/or CDMA which employing existing PSK as the primary modulation, the phase continuous PSK is able to improve robustness of frequency expansion by this harmonic power reduction in high speed running vehicle communications through multi-ray propagation environment.

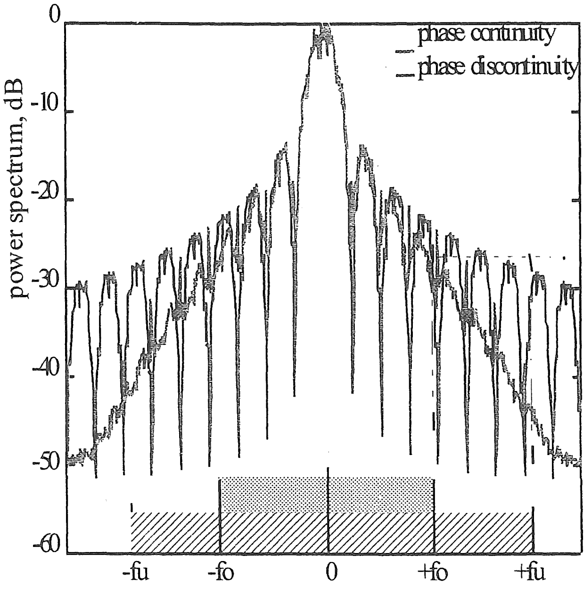

Fig.3 Frequency response comparison between phase continuous and discontinuous PSK power spectrum

2.2. CONTINUOS CHIP SHAPING IN THE SECONDARY MODULATION

CDMA being defined by convolution of the primary PSK modulation and spreading code spectrum, reduction of the secondary modulation bandwidth is also discussed here as the important problem in addition to phase continuous PSK.

Typical code waves are illustrated in fig.4. As shown by dotted lines, the existing code wave is given by square topped signal to maintain a unique value within the whole duration of every chip to cause a jump at every fringe in proportion to the chip value difference between adjacent chips. If no jumps exist at around all chip fringes, the secondary modulated signal is obviously reduced frequency occupied bandwidth to arbitrary single PSK with victim of losing code space spanning ability. It is, however, necessary to maintain individual code value at every chip center, but is sufficient to keep the same value in neighbors at the center in order to spread the spectrum of the primary modulating PSK along its individual code axis. It becomes to be possible to reduce the occupied bandwidth where the rapid variation is suppressed to yield smooth chip wave in the secondary modulation.

Continuous chip shaping is facilitated as shown in fig.4 as solid curve by substituting similar smoothing function to the continuous phase primary modulation over newly introducing transient duration spanning over adjacent chips. The smoothing function touches current and next chips at the front and tail ends with 0th order contact, respectively, and varies with the steepest gradient just at the center of the transient duration, i.e. at every fringe.

Effect of Continuous Chip Shaping

Figures 5a and 5b show the ensemble-averaged spectrum of continuous and discontinuous chip shaping, respectively. If the transient duration is expanded to the whole chip duration, the side lobes are efficiently reduced by 3.69, 13.75, and 24.59 dB at the second, third, and forth harmonics. The side lobe reduction effect is observed by more than 30 dB at the eighth harmonics with comparing those of discontinuous chip shaping.

The continuos chip shaping is recognized to reduce the excessive bandwidth expansion occurred during the secondary modulation with the victim of increasing the transient time domain for varying the chip value. Otherwise, if the chip shaping transient duration is too long beyond a priori

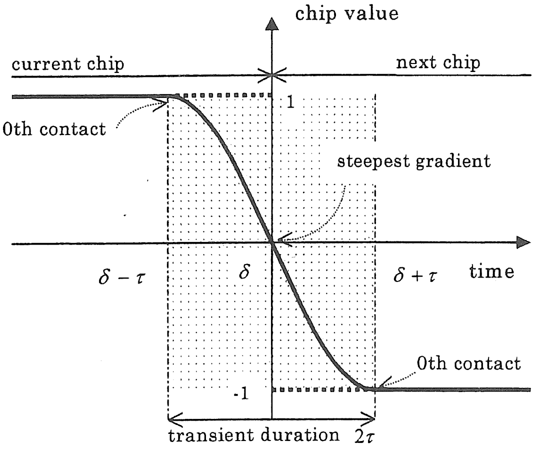

Fig.4 Illustrative time response of continuous chip.

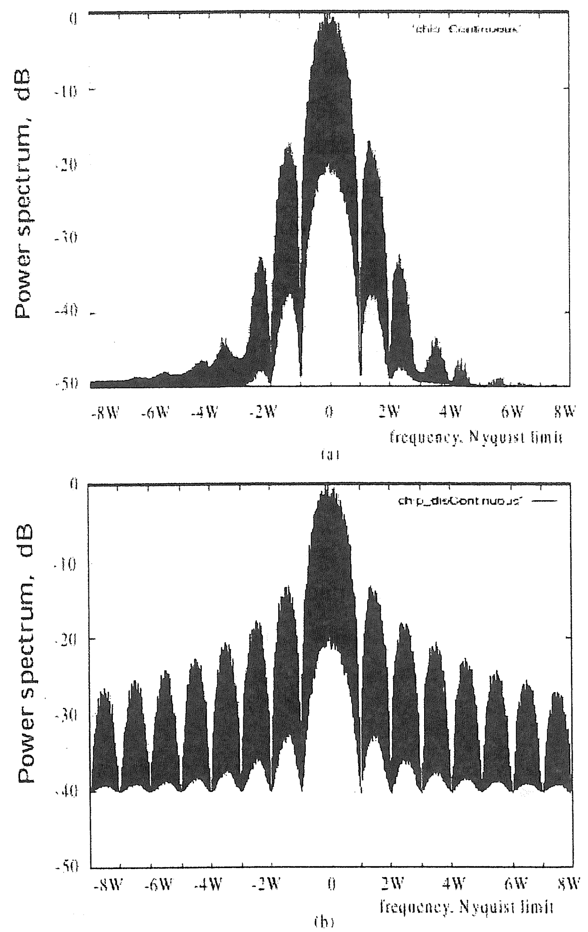

Fig. 5 Frequency response comparison between continuous chip shaping and discontinuous chip wave power spectrum, (a) chip continuous and (b) chip discotinuous.

optimum value, the subjective domain is restricted within undetectable limitation for uniformly defining chip value.

3. CDMA WITH VIRTUAL SEGMENT INTERLEAVING

3.1. Concept of Virtual Segment Interleaving

The virtual segment interleaving establishes a novel solution for efficient frequency usage without introducing any contradictions between phase continuity primary modulation and continuous chip shaping in the secondary modulation. The transmission reliability is improved with proportion to the subjective symbol chip number given by a product of effective segment/symbol and chip/segment numbers because of the random noise being averaged among the plural subjective segment. Here, the segment means the duration of given length compact Walsh code.

A compact Walsh is described by distinguishing from spatiality in code using if and only if all the code of given length Walsh is used for DS/SS. For example, 32 out of 128 Walsh code is devoted to DS/SS as a single segment scheme, it is equivalent to 4 segments of compact 32 Walsh code in spanning code space meanings. Orthogonality stands over any 32 chips successively located in multi segment compact Walsh code because of recursive structure as follows.

$$W_N = \begin{bmatrix} W_{N/2} & W_{N/2} \\ W_{N/2} & \overline{W}_{N/2} \end{bmatrix} \qquad (4)$$

here, W_N *is N length Walsh function.*

The j raw of 4 segment N length Walsh, W_j is, therefore, described in the following style.

$$W_j = \left[W_N^j \quad W_N^j \quad W_N^j \quad W_N^j \right] \quad j \le N \qquad (5)$$

Equations(5) is summing up by using larger Walsh as follows,

$$W_j = \left[W_{2N}^j \quad W_{2N}^j \right] = \left[W_{4N}^j \right] \qquad (6)$$

On the other hand, equations(5) is also decomposed into smaller Walsh as,

$$W_j = \left[W^j_{N/2} \quad \tilde{W}^j_{N/2} \quad W^j_{N/2} \quad \tilde{W}^j_{N/2} \quad W^j_{N/2} \quad \tilde{W}^j_{N/2} \quad W^j_{N/2} \quad \tilde{W}^j_{N/2} \right]$$

$$\text{Here, } \tilde{W}^j_{N/2} = \begin{cases} W^j_{N/2}, & if\ j \le \dfrac{N}{2} \\ \overline{W}^j_{N/2}, & else \end{cases} \qquad (7)$$

Finally, W_j is decomposed into order 1

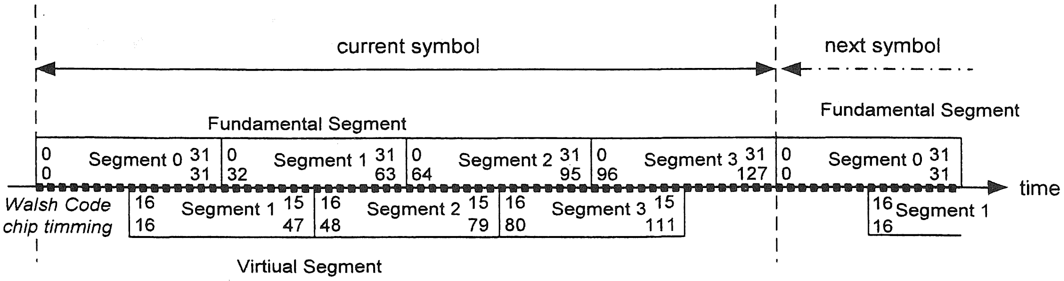

Fig.6 Virtual Segment Interleaving

scholar form as follows.

$$W_j = \left[W_1^j \ \widetilde{W}_1^j \ W_1^j \cdots \widetilde{W}_1^j \ W_1^j \ \widetilde{W}_1^j \right]$$
$$= \left[1 \quad 1/0 \ 1 \ \cdots 1/0 \ 1 \quad 1/0 \right]$$

Here,

$$\widetilde{W}_1^j = \begin{cases} W_1^j, & if \ j = 1 \\ given \ like \ LSB \ of \ j, & else \end{cases} \tag{8}$$

Any successive a quarter length of W_j gives mutually orthogonal vector with each other for every value j. Therefore, we can settle virtual segments on the chip stream of scrambling for the fundamental segments with overlaying on these 4 fundamental segments as shown in fig.6.

Cross-correlation of the random noise among these 4 fundamental and 3 virtual segments is reasonably small less than half unity. Here, the fundamental segment 0 or 1 is consists of 32 chips from 0 to 31 or from 32 to 63 chip of the inner symbol chip stream. And, the virtual segment 0 or 1 is consists of 32 chips from 16 to 47 or from 48 to 79 chip of the inner symbol chip, and so on. In the case of phase continuity transient duration being given by a quarter symbol, the fundamental segment 0 and 3 are damaged in the front-half and tail-half 16 chips over the transient duration, respectively. Otherwise, the 2 segments of the fundamental segment from 1 and 2, and all virtual segments from 0 to 2 are left as the effective segments for estimating receiving signals to improve the transmission reliability.

3.2. CIRCUITRY CONFIGRATION OF VSI

The system configuration of the CDMA with proposing VSI is illustrated in fig.7 as significant functional block diagrams. As shown in fig. 7a for the transmission module of diffCDMA-VSI, the circuitry

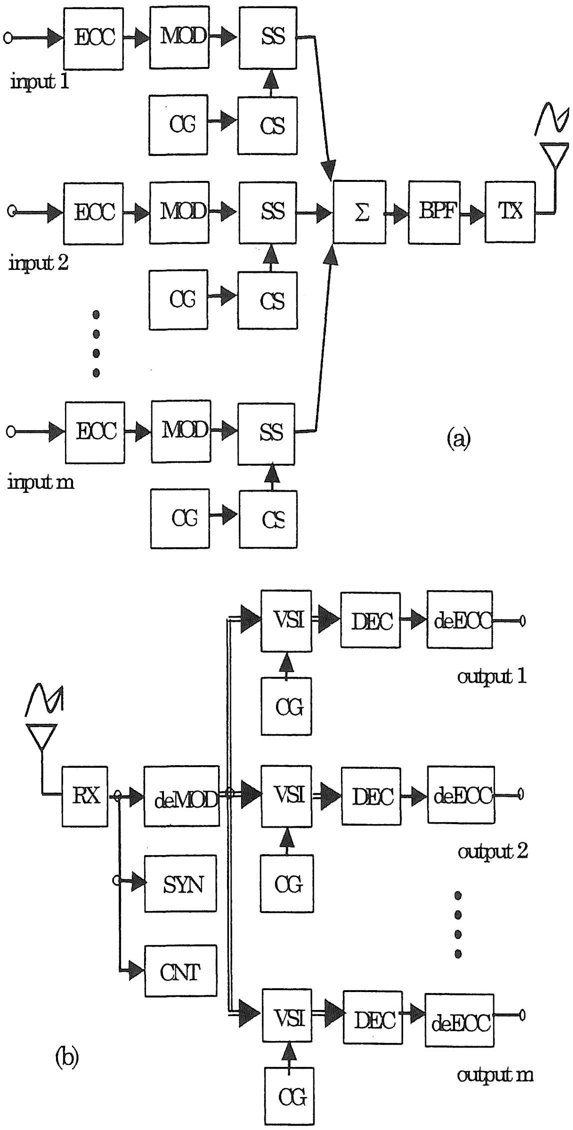

Fig.7 Block diagram of continuous chip shaping CDMA, m speech channel transmission module (a), and m' speech channel receiving module (b).

skeleton is same to those of diffCDMA.

CS is a continuous chip shaping circuit interpolated between spectrum spreading code generator CG and the secondary modulator SS for every transmission channel. ECC is pre-fixed to the primary modulator MOD to yield double error correction BCH (63,51) code along to individual bit string. That is, two ECC will be employed for each spectrum spreading code if the primary modulation is performed as QPSK. Here, mark MOD, Σ, or BPF means the primary PSK modulator, adder or band-pass filter, respectively. And, the total number of transmission channels is m.

Circuit topology of the receiving module of the diffCDMA-VSI is same as shown in fig. 5b to the receiving module of diffCDMA with exception of virtual segment interleaving circuit, VSI. Mark RX, SYN, CNT, CG, DEC, or deECC means the receiving unit, synchronization detector, control signal recovery circuit, the primary demodulator, spectrum despreading code generator, decision circuit, or double error correction decoding circuit for BCH (63,51) code, respectively. Circuitry configuration is shown in fig.8 in details for VSI function block. The product of demodulated signal, i(t) or q(t), and deDS/SS code is accumulated in the double buffers, ACUM, in corresponding to the fundamental and virtual segments. In fig.7, mark SEL, DMPX, CNT, or DMPL is selector, chip counter, or de-multiplexer, which are consist of the double buffer. Here, the total receiving speech channel is m'.

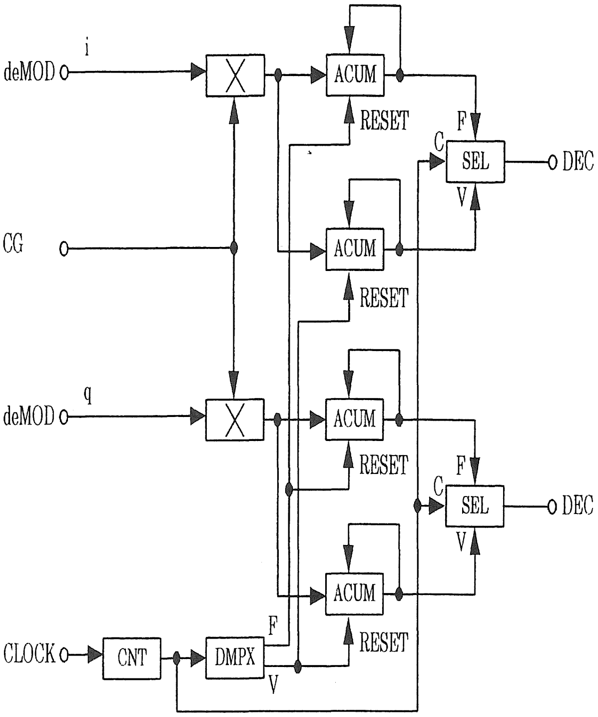

Fig.8 Block diagram of Virtual Segment Interleaving with deSS.

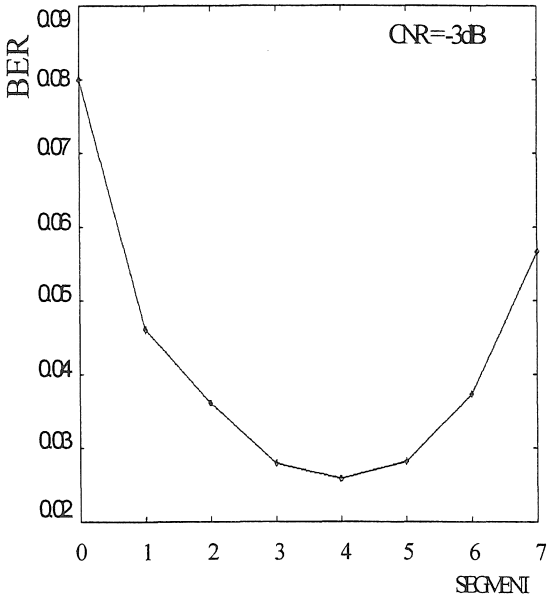

Fig.9 BER vs. segment at CNR= -3dB.

In general speaking, the transmission channel number m is required to be larger than receiving speech channel m', even if the maximum transmission capacity is achieved in the case of m being equal to m'. In fact, control and synchronization carry through these redundant m-m' channels both in cdmaOne and WcdmaOne, or carry by redundant time slot shared by time compression to yield equivalent redundancy both on time and frequency space in Wide CDMA, in which m is at a glance nearly equal to m'.

Fortunately, a novel CDMA system, named by diffCDMA, has successfully excluded redundancy of the channel or time slot as previously reported. This diffCDMA is categorized into an enhanced system of WcdmaOne from transmission and signaling points of views. The maximal transmission capacity is given by 1.66Mbps where BCH (63,51) ECC being adopt, the bandwidth is restricted within 4 MHz over transmission channel, and chip rate is 4Mcps if 4 fundamental segments being employed in every symbol.

4. SIMULATION RESULTS

The VSI is able to improve transmission reliability without introducing any circuitry complexity at sending module and slight victim of adding double buffer at receiving module. The subjective segments for detecting symbol value is consequently reduced after introducing phase continuity in the primary modulation. That is, the stronger the segments neighbor to the symbol fringe are damaged from the phase distortion for continuity, the smaller the random noise being averaged in small segments around at symbol center.

Figure 9 shows the relation between BER vs. segments number at receiving level of CNR=-3dB. While the segment number changes from zero to 7, the BER shows a trade-off as showing virtual segment interleaving effect at around 4 like a priori expectation. If segment number is expanded to 7, a few segments are damaged from phase continuity. On the other hand, if one segment is employed, the BER is degraded from weakness in smoothing random noise induced during propagation over poor radio channel. Simulation results are shown in fig.10 to improve two-ray Rayleigh fading robustness by vanishing any bit errors via employing continuous chip shaping, phase continuous QPSK, and BCH (63, 51) ECC at CNR=10.0dB if communications being carried from 10 km/h walking pedestrians. BER is null at CNR=15.2dB if from 100 km/h running vehicles, or at CNR=17.5 dB if from 1,000 km/h flying aircraft through the urban environment mentioned in the above. In discussing diffCDMA, 64 bits are simultaneously carried through 32 code channels, BER is observed to be null in Eb/No meanings at -8.0dB for pedestrian, at 2.8dB for vehicles, or 0.5dB for aircraft after compensation by 10log64, respectively.

CONCLUSION

The newly proposing diffCDMA with virtual segment interleaving has been successfully discussed in this paper with emphasis both on realizing bullet train and aircraft 1.6 Mbps CDMA communication system. The diffCDMA-VSI is able to put high capacity and high speed CDMA communication on the developing stages with employing such novel techniques as continuous chip shaping, phase continuous primary modulations, virtual segment interleaving, and BCH double error correction.

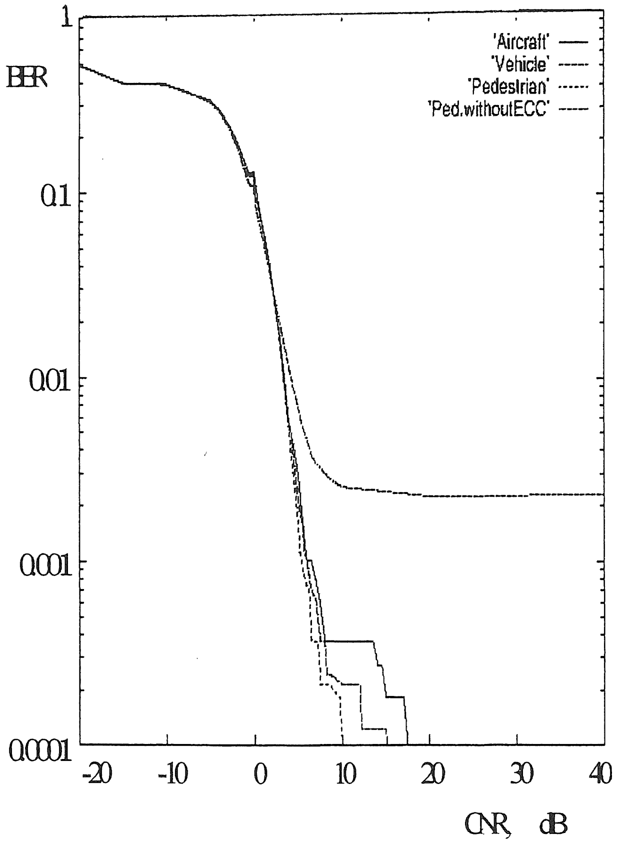

Fig.10 BER vs. CNR response comparison among aircraft, vehicle, and pedestrian communication of double error correction1.6Mbps/ 4.096MHz diffCDMA through two-ray Rayleigh environment with 0.5 micro second delay spread.

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