

Wideband Spread Spectrum Modulation for Higher-Data-Rate Mobile Communications

Yumi Takizawa, Saki Yatano, Atushi Fukasawa

Abstract— This paper describes some results of study on spread spectrum modulation method for higher-data-rate transmission. This scheme is expected useful against multipath radio propagation in urban mobile radio communication. Characteristics of wideband spreading were first evaluated. A novel configuration with matched filters is described for efficient and reliable synchronization under multipath environment. A prototype hardware was fabricated with new configuration. Expected system capability was lastly estimated based on system size and data rate.

Keywords— wideband spread spectrum modulation, multipath radio propagation, synchronization, matched filter, high-data-rate transmission

I. INTRODUCTION

Mobile radio communications are now major in public communications. High-speed-data and high quality pictures will be expected for public mobile communications in the next generation.

Modulation scheme of microwave radio waves is essentially important to solve degradation of transmission data rate and reliability caused by multipath radio propagation. The orthogonal frequency division multiple access (OFDM) scheme are now popular for high speed for short distance radio LAN supported by multilevel modem and MIMO technologies.

Next generation system is considered with radio technology by OFDM and software technology toward seamless network. Spatial, popular, and economical difficulties will be caused by depreciation of degradation of communication quality caused by multipath radio interference.

In this paper, a scheme of spread spectrum modulation technologies is taken up on the view point of signal processing capability of multipath radio transmission components. Each component is collected to elevate signal energies against

constant receiver noise toward lower BER and power consumption.

II. THEORY AND PRACTICE OF WIDEBAND SS MODULATION

A. Theory of SS modulation

Spectrum of waveform signal is spread by direct modulation with orthogonal code waveform. User number and radio transmission channel are assigned sequentially by pseudo noise (PN) and Hadamard sequence (Walsh) codes. The former is incompletely, and the latter is completely orthogonal.

Quadrature Phase Shift Keying (QPSK) modulation is used for RF modulation. Transmission data is divided into two streams of in-phase and orthogonal phase components a, b respectively. The RF modulator of a transmitter outputs the following signal.

$$x(t) = (a + jb)\phi(t)\psi(t) + \phi(t) \quad (1)$$

where, $\phi(t), \psi(t)$ are PN and Walsh codes. A receiver inputs the following signal.

$$y(t) = \{(a + jb)\phi(t)\psi(t) + \phi(t)\}\gamma \exp(j\theta) \quad (2)$$

where, γ, θ are the amplitude and phase characteristics of radio propagation. The following processing is done.

$$\begin{aligned} u &= \frac{1}{T} \sum \phi(t)\psi(t)y(t) \\ &= \frac{1}{T} \sum \phi(t)\psi(t)\{(a + jb)\phi(t)\psi(t) + \phi(t)\} \cdot \gamma \exp(j\theta) \\ &= \left\{ (a + jb) + \frac{1}{T} \sum \psi(t) \right\} \gamma \exp(j\theta) \\ &= (a + jb)\gamma \exp(j\theta) \end{aligned} \quad (3)$$

where, the following relationship is used,

$$\frac{1}{T} \sum \phi^2(t) = 1, \frac{1}{T} \sum \psi^2(t) = 1, \frac{1}{T} \sum \psi(t) = 0$$

and

$$\begin{aligned} v &= \frac{1}{T} \sum \phi(t)y(t) \\ &= \frac{1}{T} \sum \phi(t)\{(a + jb)\phi(t)\psi(t) + \phi(t)\} \cdot \gamma \exp(j\theta) \end{aligned}$$

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$$\begin{aligned}
 &= \left\{ (a + jb) \frac{1}{T} \sum \psi(t) + 1 \right\} \gamma \exp(j\theta) \\
 &= \gamma \exp(j\theta)
 \end{aligned}
 \tag{4}$$

The following are calculated based on the above results.

$$\begin{aligned}
 \hat{d} &= v * u \\
 &= (a + jb) \gamma \exp(j\theta) \gamma \exp(-j\theta) \\
 &= \gamma^2 (a + jb)
 \end{aligned}
 \tag{5}$$

Eq. (5) includes the information of phase rotation through a radio propagation. The characteristics of propagation are calculated by Eq. (4), which compensates the phase rotation. Finally transmission data can be demodulated without distortion.

B. Practical configuration

Practical configuration is shown in Fig.1[1]. At modulation side, transmission data $d(t)$ is converted with digital operations into QPSK components a (I-phase) and b (Q-phase).

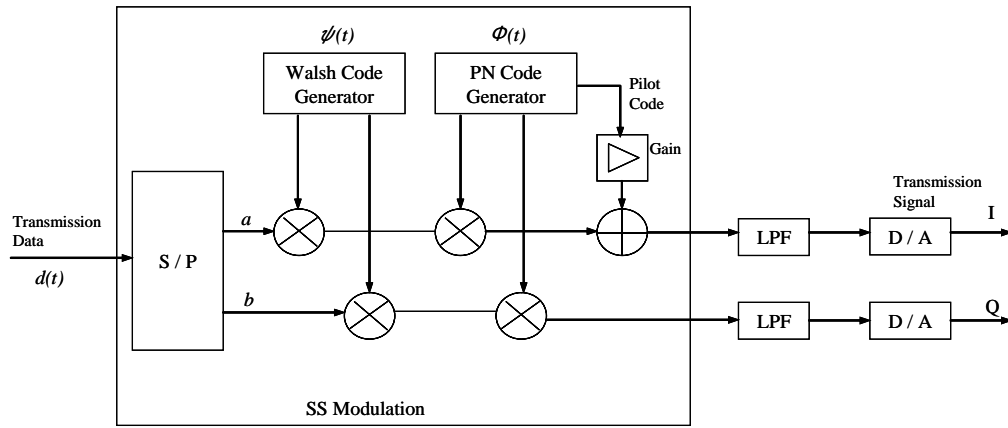
Orthogonal codes $\psi(t)$ and $\phi(t)$ are applied for I and Q components for SS modulation. Walsh code $\psi(t)$ is completely orthogonal and assigns scarce number of radio transmission channels. PN code $\phi(t)$ is incompletely orthogonal and assigns huge number of subscribers.

In this system a pilot signal is also transmitted with known PN code for system synchronization and coherent demodulation.

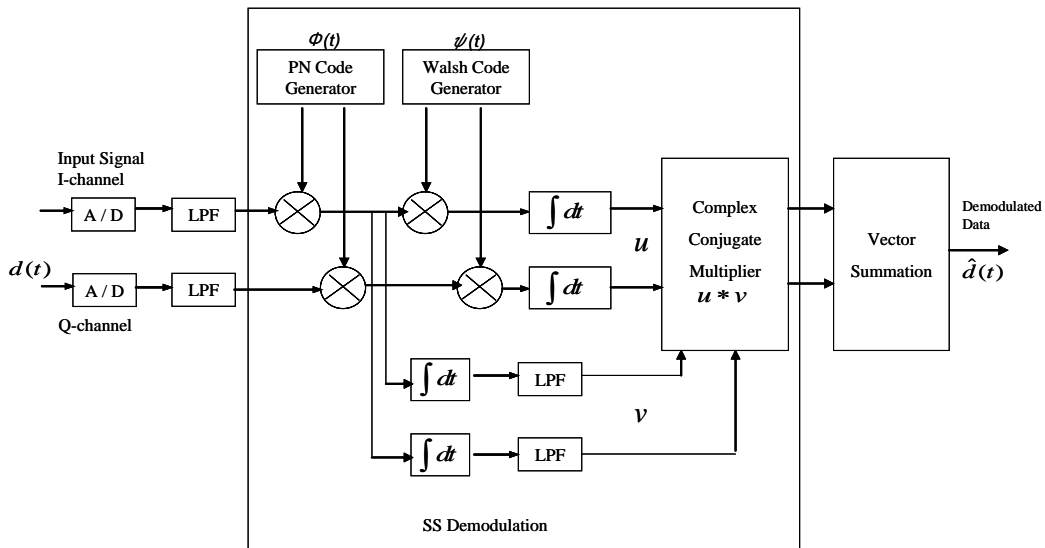
At demodulation side, correlation of received signal and a replica of pilot signal are calculated to generate clock (timing) signal. Correlation is done by the operation of multiplication and integration

All processing is done by digital calculations with this clock signal.

Accuracy and resolution of timing of each of multipath components specifies capability of transmission data rate with reliability of mobile communication. In this study, an analog matched filter system is taken up in place of conventional digital signal processing to enhance system capability for high data rate transmission [2].



(a) Configuration of Wideband SS modulation.



(b) Configuration of Wideband SS demodulation.

Fig.1 Configuration of Wideband Spread Spectrum scheme.

C. Synchronization with A Matched Filter System

Extremely short time of data processing is required especially for synchronization and coherent demodulation compared to other processing and operations.

Over sampling and long timeframe are needed to extract correlation peaks with fine resolution and precise value of time.

It is found by computer simulation of synchronization, one sampling times 1024 chips is required for cell synchronization (cell site and mobile), four sampling times and 256 chips for path synchronization (radio propagate paths between cell site and mobile) are needed at least. The resolution of time of path synchronization is required for vector combining of multiple paths.

A matched filter system is developed and introduced into synchronization and demodulation in this scheme. The configuration is shown in Fig. 2.

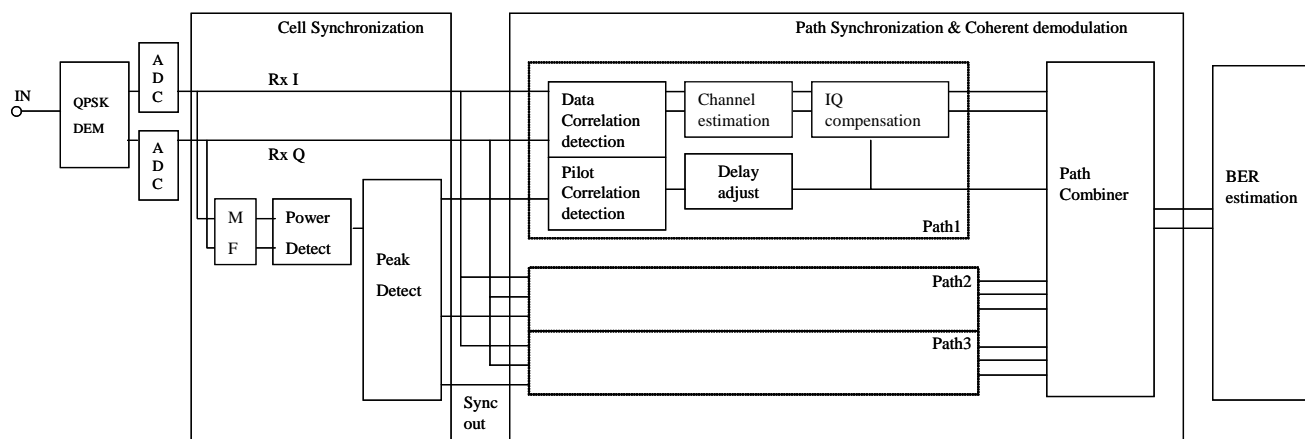


Fig.2 Configuration of synchronization and coherent demodulation for the enhanced W-CDMA.

B. Characteristics of Wideband SS Modulation

Characteristics of wideband spreading evaluated with a novel configuration of enhanced W-CDMA. A new system is composed of a system of parallel matched filters. In this evaluation four parallel matched filters is used and each parallel matched filters is composed of 256 taps.

The characteristics of wideband spreading are shown in Fig.3. The radio bandwidth is assumed 5 and 15MHz, which are assigned for personal communications service (PCS) in North America. The data rate of transmission is chosen and multiple times of natural number of 64 Kbit/s.

For this study, automatic observation system has been developed to observe fundamental measures of characteristics of hardware. Eye pattern and BER value, QPSK constellation

III. SYSTEM CONFIGURATION OF ENHANCED W-CDMA

A. Configuration of the system

Due to multipath propagation and Doppler effect, it is important to establish accurate synchronization. A new scheme is provided for synchronization to improve characteristics using a delay profile with reduced steps of processing. A parallel matched filter is configured by analog signal processing instead of conventional digital components[2][3][4].

The power consumption and dimension of the LSI are reduced effectively by the mixed approach of the system and the hardware. Finally, this paper describes feasibility of the high speed data transmission on the W-CDMA system.

and demodulated data on complex plane are shown automatically by windows personal computer through PCI bus connected to FPGA board of enhanced W-CDMA hardware.

By the result of numerical calculation and observation by the automatic observation system, it is found that spreading bandwidth should be about 0.8 and spreading gain should be about 12 or larger.

Achievement of higher-data-rate than the above at given bandwidth is under study on both domains of system and hardware [5][6][7][8][9].

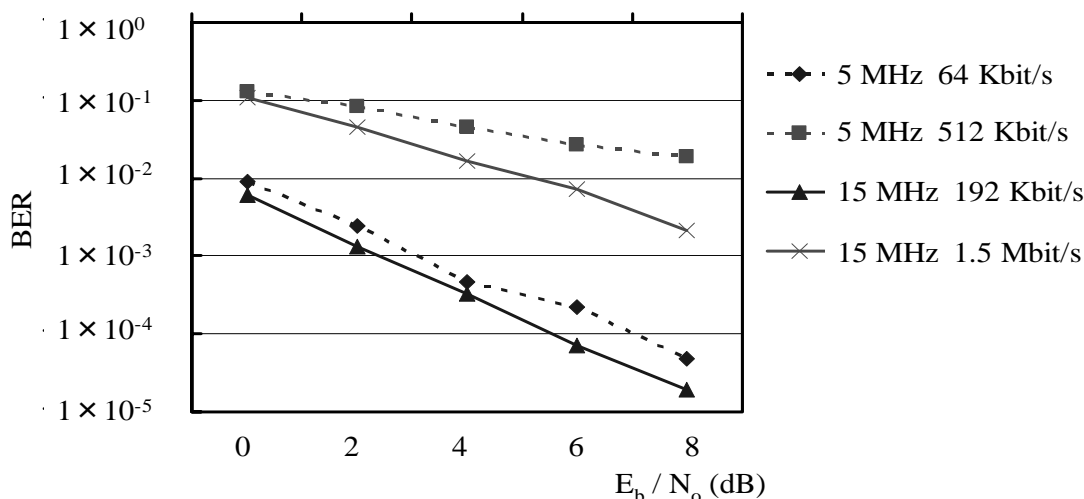


Fig.3 Characteristics of BER vs. E_b / N_o (dB).
Radio bandwidth 5 and 15MHz

IV. PROTOTYPE HARDWARE

A. Radio system design

The W-CDMA was first presented for the personal communication services by the authors [1]. This scheme is featured by spectrum spreading to radio frequency wideband, and coherent demodulation by using a pilot channel. The system configuration of the enhanced W-CDMA is shown in Fig.2.

Coherent demodulation scheme is composed as follows. (i) Continuous pilot signal is transmitted through a pilot channel, (ii) the pilot channel is composed of O-QPSK and QPSK for reverse and forward links respectively, (iii) pilot signal is added in each I channel of O-QPSK and QPSK, (iv) coherent demodulation is achieved by estimation and compensation of phase rotation using the pilot channel.

Phase rotation and its linearity have been estimated for QPSK and O-QPSK data modulation methods. The constellation on the complex plane is used for the evaluation of phase rotation, and the Eye pattern for the demodulated waveforms. The bit-error-rate (BER) vs. E_b/N_0 is used for the characteristics of data modulation / demodulation and SS modulation / demodulation of the enhanced radio system.

Interference canceller is also studied for increased capacity in future. This also is based on the pilot channel to decide timing of each component of matrix of radio channel models with multiple transceiver.

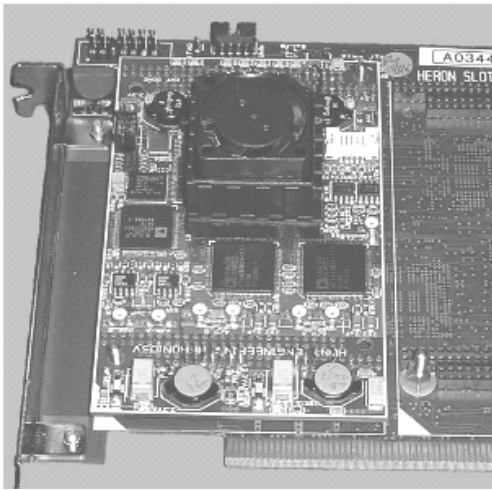
B. Implementation of Prototype Model

This work is concerned with wideband spread spectrum modulation and Code Division Multiple Access technologies for the next generation wideband radio system. Feasibility of this scheme depends on rate of processing, power consumption, and volume size of electronic circuit and processors.

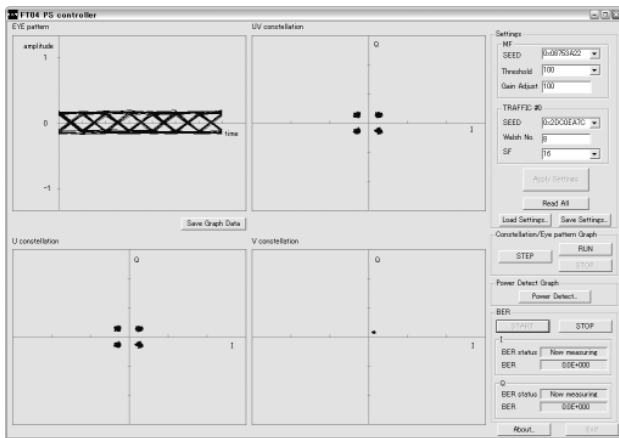
As an available processor, field programmable gate array (FPGA) is adopted to validate utility of proposed the scheme, expecting cooperation with commercially available MPU. Complex and large quantity of processing steps is actualized by FPGA, and flexible management of data and process are done by micro processor unit (MPU).

Prototype hardware was implemented as shown in Fig.4. This hardware was developed by the aid of automatic characteristic monitoring system with registers fabricated in FPGA board and read and write access software fabricated in a personal computer. The choice of FPGA and MPU with CMOS technologies is an ideal way at this moment, choice of customized CMOS circuit and embedded system will be final way to meet the requirement said about.

A prototype model is designed for 40 MHz and 5 MHz bandwidth for the forward and reverse links at 3.5 GHz radio frequency band. Variable data rate is adopted at multiple times of 64 Kbit/sec. The data rate of 64 Kbit/sec ~ 32 Mbit/sec is designed to the forward link for download of broad band data of high quality video data.



(a) A prototype hardware.



(b) Output of Automatic observation system.
 Eye pattern of demodulation [left upper]
 Constellation of modulation [right upper],
 Constellation of demodulation [left lower],
 Received data of complex number [right lower],

Fig.4 a prototype hardware implemented by a FPGA board

V. STUDY ON NEXT GENERATION SYSTEM

A. Microwave Frequency Allocation and Bandwidth

Micro wave diffraction is essentially expected against relief of terrain and buildings, propagation distance is about 1~several kilometers for public mobile communications. The frequency band should be allocated at 1~3.5 GHz (wavelength 3~1 meters). Figure 1 illustrates transition of microwave and frequency bandwidth. In this study the suitable frequency band is 3~3.6 GHz, and the frequency bandwidth is 40 MHz, if needed up to 100MHz for download of broadband data and high quality pictures.

Communication, information (IT), and broadcasting have been separated services provided to citizen conventionally. They are now expected to be unified and merged to support near future the citizen lives.

Great parts of citizen are well furnished with compact equipments for communication. Personal computers are also popular for business life in the office, but they are limited for mobile use. One of the pointed problems for IT area is the matter of digital divide among citizens in daily life. One of the problems of computers is the engineering problem to provide compact equipment with high performance and small power exemption. The other is difficulties of handling of computers. The target of this study is to provide technologies merging the communication and the IT for public people use.

Ubiquitous communication network system is provided both of advanced communication and computer technologies.

B. Wideband Mobile Radio System

Initial video services are introduced in cellular mobile system to enhance the capability of communications. These services are limited in size of contents, which lead to reduce display size and text based internet menu etc. Scaling up of picture size degrades its quality rapidly.

Assumed area of the enhanced radio air interface is shown in Fig. 5. The horizontal and vertical axes are data rate (bit / s) and distance of communication (m) respectively. The low area is assumed to radio LANs. This study intends to be applied to public mobile communications down on the upper part of Fig.5. At public domain the latest scheme is the W-CDMA proposed and validated by the authors [1][10][11]. At radio LAN domain, the latest scheme is the OFDM, which has ever proposed at low quality wired MODEM, applied to first digital broadcast and to now radio LAN.

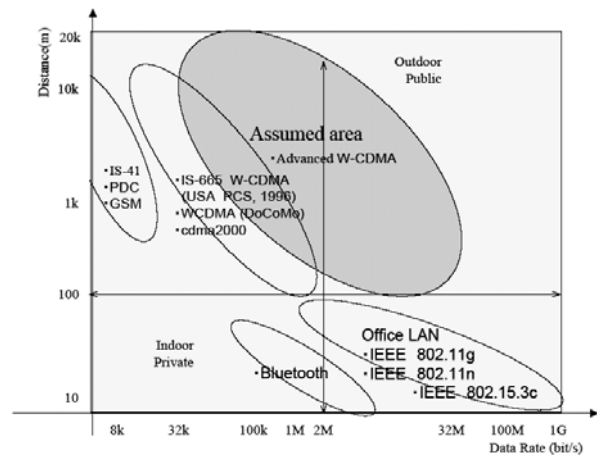


Fig.5 Assumed area of mobile communication in the next generation.

VI. CONCLUSION

Some results of studies has been shown on spread spectrum (SS) modulation technology. This study is conducted for higher data rate transmission by next generation mobile communication. This scheme is only one method to solve program of multipath radio propagation to bring degradation of higher data rate transmission quality. Characteristics of wideband spreading are first evaluated. A novel configuration with matched filters is shown for efficient and reliable synchronization under multipath environment. A prototype hardware was also presented designed by new configuration. Useful and effective result of study was proved by computer simulation and implementation of prototype hardware. Improvement of higher data rate is under the study.

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