行政院國家科學委員會補助專題研究計畫成果報告

IMT-2000 軟體無線電架構之研究 (III)
-子計畫六:多碼/多速率分碼多工之多媒體通訊

計畫類別：□個別型計畫　　ο 整合型計畫
計畫編號：NSC 89－2219－E－002－033
執行期間：　89 年 8 月 1 日 至 90 年 7 月 31 日

計畫主持人：陳光禎教授

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執行單位：國立台灣大學電信工程研究所

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IMT-2000 軟體無線電架構之研究(III)-子計畫六:多碼/多速率分碼多工之多媒體通訊

Multi-Code/Multi-Rate CDMA Multimedia Communication (III)

計畫編號：NSC 89-2219-E-002-033

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一、 摘要

Two multi-rate transmission schemes, multi-code (MC) and variable spreading length (VSL), for realizing multimedia communications on three types of OFDM-CDMA systems are proposed separately. We integrate them into a programmable structure such that the operation can be controlled and adjusted by system parameters and thus the transceiver can be used in different systems without changing the fundamental hardware and software architecture, which satisfies the trend of software-radio for future applications.

Keywords: CDMA, OFDM, multi-rate, OFDM-CDMA, software radio, multi-code, variable-spreading length code, multi-media communication

二、緣由與目的

Multimedia communication will be the main stream in the future communication services and it introduces challenges in effective transmission. As code-division multiple-access (CDMA) being utilized for the third generation and future communication systems, it is an important subject to realize multimedia services based on CDMA. Among the previous researches, Multi-Code (MC) and Various-Spreading-Length (VSL) access schemes are the two most fundamental and widely applied multi-rate schemes [1]. On the other hand, Orthogonal-Frequency-Division- Multiplexing (OFDM) has been widely used in high-speed digital communications, which can be implemented efficiently by the digital technique of Fast-Fourier-Transform (FFT)[2] and known as a solution to combat the problem of the highly hostile mobile channels in high-speed transmissions. Furthermore, combining CDMA and OFDM results in finer partition of radio resource, which makes the resource allocation more effective. Therefore, OFDM-CDMA for multimedia applications is an attractive candidate for the 4th generation wireless communication systems and its realization by a flexible software-defined architecture is of significant interests. Recent years, multiple access schemes based on the combination of CDMA and OFDM have been proposed, and they can be generally divided into three types, namely MC-CDMA [3], MC-DS-CDMA [4], and MT-CDMA [5] respectively [6]. To realize multi-data-rate transmission, we separately proposed two transmission methods, based on MC and VSL strategies, for the three OFDM-CDMA scenarios. Finally, we integrate them into a programmable structure such that the operation can be controlled and adjusted by some parameters and thus the transceiver can be used in different systems without changing the fundamental hardware and software architecture, which satisfies the trend of software-radio for future applications.

Assume the data rate of each user is an integer multiple m of the basic data rate. The proposed transmission method by MC access scheme is illustrated in Fig. 1. Each data stream is first divided into m effective data streams and then treated individually by the standard procedure of any OFDM-CDMA scenario. The transmission method by VSL access scheme is depicted in Fig. 2. Unlike the MC access scheme, the data streams are not multiplexed into basic-rate streams but spread by various length of spreading codes corresponding to

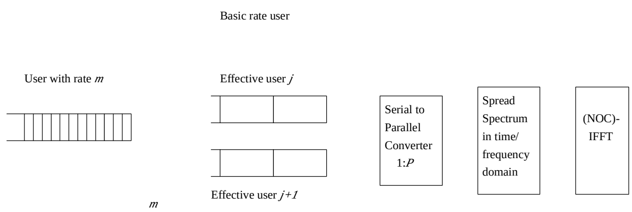

Fig. 1. Multi-Code access method for OFDM-CDMA.

the data rate in the following OFDM-CDMA operation to keep the bandwidth and spectrum profile fixed.

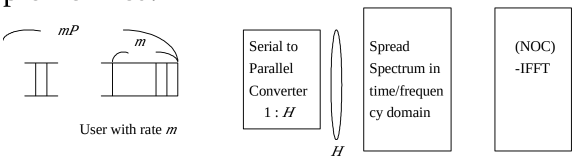

Fig.2 Variable-Spreading-Length Access of OFDM-CDMA. $H=mP$ in MC-CDMA; otherwise $H=P$

三、結果與討論

Two multi-rate access strategies and three OFDM-CDMA methods result in totally six multi-rate OFDM-CDMA scenarios.

Programmable OFDM-CDMA transmitter

The proposed architecture of programmable transmitter is depicted in Fig. 3, which also shows the control functions, F1~F6, that should be executed in operation. Each function can be adjusted by some parameters, which includes: choice of access scheme, choice of adopted OFDM-CDMA scheme, data rates, and the spreading factors of each data stream. These functions are defined as:

F1: It determines the number of enabled Main Branches (MB). It is executed on a multiplexer after receiving the data stream from a user. If the system is operated on multi-code access mode, it multiplexes the data stream into m sub-streams by enabling m branches. If it operates on VSL mode, just forward the data stream on one branch.

F2: It determines how many Parallel Output Branches (POB) corresponding to the S/P ratio will be enabled. Only under the scenario of VSL-MC-CDMA, POB is set to be mP; otherwise, POB is P.

F3: Function 3 determines the number of enabled Sub-Branches (SB), which is a copy of the former stream, of each POB and the type of spreading. If the scenario is MC-CDMA, the enabled SB is F for multi-code access and F/m for VSL access. If the scenario is MC-DS-CDMA and MT-CDMA, SB is L[1] and 1 respectively for both access methods. Cyclical multiplying by corresponding codes on each SB is set for MC-DS-CDMA and MT-CDMA. In MC-CDMA mode, signal on each SB is spread by multiplying one corresponding bit of spreading codes.

F4: To satisfy the required number of parallel inputs for IFFT operation, function 4 pads zeros according to the selected scenario, which results in regular padding for regular IFFT and circular-shift padding for NOC-IFFT. The circular period is F in MC mode and F/m in VSL mode. In example of radix-2 algorithm, the number of Padded Zeros (PZ) should be $2^{\lceil \log_2 N_b \rceil}$-$N_b$ in regular IFFT, where N_b denotes the number of parallel inputs. For NOC-IFFT operation in MT-CDMA modes, PZ should be $F\left(2^{\lceil \log_2 N_b \rceil} - N_b\right)$ and allocated in circular-shift type.

F5: Function 5 decides the number of operation points (OP) in IFFT for each scenario. OP equals the number of outputs in F4.

F6: Function 6 determines the enabled input branches of the P/S converter and the conversion ratio at different scenarios.

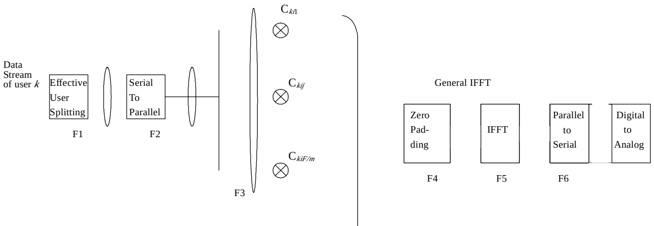

Fig. 3 The structure of the programmable OFDM-CDMA transmitter

Table 1 summarizes the parameters of F1~F5 in different scenarios, the operation period in F6, and the resultant bandwidth. The defined notations:

MC: multi-code,

VSL: Variable-Spreading-Length

A:MC-CDMA, B:MC-DS-CDMA, C:MT-CDMA

m: data rate in unit of basic rate

F: spreading factor of a basic data-rate user

L: the diversity expansion of MC-DS-CDMA

CNS: constant bit multiplying, CYC: cyclical multiplying

Table 1.

scenario	F1 MB	F2 POB	F3 SB	F4 PZ	F5 OP	F6 Period	Bandwidth
(A, m, MC)	m	P	F; CNS	$2^{\lceil \log_2(PF) \rceil}$-$PF$ regular	$2^{\lceil \log_2(PF) \rceil}$	PT_s	$\frac{PF-1}{PT_s}+\frac{1}{T}$
(A, m, VSL)	1	mP	F/m; CNS	$2^{\lceil \log(_2 PF) \rceil}$-$PF$ regular	$2^{\lceil \log(_2 PF) \rceil}$	PT_s	$\frac{PF-1}{PT_s}+\frac{1}{T}$
(B, m, MC, L)	m	P	L; CYC	$2^{\lceil \log(_2 PL) \rceil}$-$PL$ regular	$2^{\lceil \log(_2 PL) \rceil}$	PT_s/F	$\frac{(PL-1)F}{PT_s}+\frac{1}{T}$
(B, m, VSL, L)	1	P	L; CYC	$2^{\lceil \log_2(PL) \rceil}$-$PL$ regular	$2^{\lceil \log_2(PL) \rceil}$	PT_s/F	$\frac{(PL-1)F}{PT_s}+\frac{1}{T}$
(C, m, MC)	m	P	1; CYC	$F\left(2^{\lceil \log_2 P \rceil} - P\right)$ circular-shift(F)	$F2^{\lceil \log_2 P \rceil}$	PT_s/F	$\frac{P-1}{PT_s}+\frac{1}{T}$
(C, m, VSL)	1	P	1; CYC	$F\left(2^{\lceil \log_2 P \rceil} - P\right)$ circular-shift(F/m)	$F2^{\lceil \log_2 P \rceil}$	PT_s/F	$\frac{P-1}{PT_s}+\frac{1}{T}$

[1] If the transmission diversity is expended with a factor L, each sub-stream before spreading stage should be copied into L identical branches [9].

According to the scenario selection, appropriate parameters and subroutines are chosen and adjusted to perform these functions by micro-controller or by DSP. Briefly speaking, these parameters determine the number of enabled hardware branches, the diversity in transmission, zero padding, the time-domain or frequency-domain spreading, and the spectrum profile.

Programmable OFDM-CDMA receiver

The same as transmitting, there are six receiving variations should be accommodated for six system scenarios. A software-based Rake receiver is illustrated in Fig. 4. Due to the principle of OFDM transmission, the number of sub-carrier is generally selected that signals on each sub-band suffer from frequency- nonselective fading. Therefore, only one finger is sufficient for most cases. However, there may be some situations that the fading in sub-bands is hard to be maintained frequency-nonselective. Thus, the number of turned-on fingers could be a pre-defined value or is controlled by the result of channel estimation to combat multi-path effect. The delays between fingers are also adjusted according to the estimation result. Fig.5 depicts the programmable structure of the fingers, where eight functions, F1~F8, are defined. The decision of symbol detection could be used for next step synchronization if the precision is high enough. These functions are defined as:

F1: It controls the sample rate of the received signals according to the selected scenario, including the required number of input in the following FFT.
F2: Function 2 determines the ratio of S/P conversion and the number of parallel outputs (PO) according to the selected scenario.

F3: Function 3 decides which type of FFT will be executed. It consists of two sub-functions where the first performs circular-shift zero padding for MT-CDMA modes and the second determines the operation points of FFT device. General FFT operates in NOC form for MT-CDMA modes and in regular form for MC-CDMA and MC-DS-CDMA modes by disabling the first sub-function.
F4: Function 4 controls the filtering of samples after FFT to discard the signals out of the sub-bands and determines the enabled tapped-delay-lines. The pass window (PSW) of zero forcing equals the number of sub-carriers used in transmission.
F5: Function 5 is executed in the dispreading stage such that each output of F4 is despread according to the spreading type (constant or cyclic type) of the selected scenario by multiplying the corresponding codes. The despreading structure is a tapped-delay-line (TDL) form and the number of enabled TDL equals ZFW in F4. F5 determines the number of enabled tap (ET) and the time spacing (TS) of each tap. For MC-CDMA modes, only one tap is needed and each line corresponds to one bit of the spre ading codes. For MC-DS-CDMA and MT-CDMA modes, the number of taps in each line equals the spreading factor.
F6: Functions 6 determines the sampling rate (SR) for taking samples on each line at the dispreading stage. The sampling rate equals the OFDM symbol duration.
F7: Based on the collection of samples from each line of all fingers, the detector makes symbol decision by combining these diversities. Different combining methods could be applicable in this stage by DSP.
F8: It controls the de-multiplexing in multi-code mode to reconstruct the original data sequence from the effective streams.

The software architecture of the proposed programmable multi-rate OFDM-CDMA transceiver can be realized by the general hardware structure in [7] as an extension. Different scenarios have different requirement of bandwidth and sampling rate. Due to the accommodation of the six multi-rate OFDM-CDMA scenarios, it forces the specification of the D/A converter and the low-pass filter should satisfy all the requirements. Thus, the D/A converter should support input rate higher than any possible sampling rate and the bandwidth of the low-pass filter should accommodate all scenarios. Another practical issue is the peak-to-average power (PAP) ratio problem, which causes the inefficiency of power amplifiers in RF. The PAP problem exists inherently in OFDM systems and can be reduced by techniques such as signal distortion, error correcting, and scrambling [8]. However, the introducing of multi-rate traffic challenges the power AMP severer. Among these scenarios, multi-code access may cause larger instant power due to its concept of parallel transmission. Therefore, we should select a power AMP whose linear range could accommodate the largest requirement of multi-rate transmission under the aid of PAP reduction mechanisms.

To eliminate the inter-symbol interference and inter-carrier interference, a guard time T_g, which is larger than the multi-path spread of channels, should be added on each OFDM symbol after P/S conversion in the transmitter and the corresponding removing should exist before F1 in the receiver. After cyclic guard time extension, the OFDM symbol duration T will be $PTs+Tg$ in MC-CDMA, and $PTs/F+Tg$ in MC-DS-CDMA and MT-CDMA. In addition, to improve the performance, some techniques such as forward error control (FEC) and interleaving could be easily added to this structure without any difficulty. Processing delay is a major challenge in OFDM systems, especially sensitive in real-time applications. In fact, this programmable transceiver supports the possibility that the number of sub-carriers could be adjusted dynamically according to the channel conditions such that the least sub-carriers attain frequency-nonselective fading at each sub-channel. In the same way, delay-sensitive data transmission is realizable by reducing the number of sub-carriers with the aid of more fingers in Rake receiving.

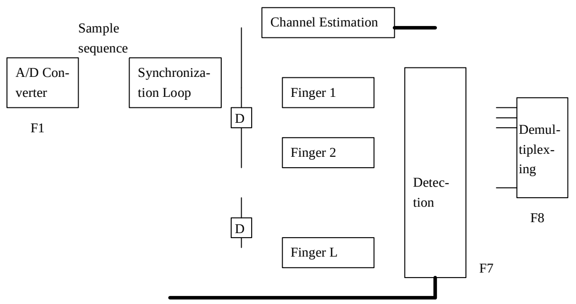

Fig. 4 The architecture of the programmable digital Rake re-

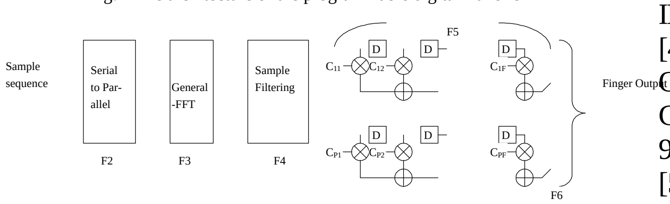

Fig. 5 The general structure of the finger of Rake receiver for programmable

<u>Table 2</u>.

	F1 Sample Rate	F2 PO	F3 IFFT	F4 PSW	F5 ET; TS	F6 SR
(A, m, MC)	$2^{\lceil \log_2(PF) \rceil}/PT_s$	$2^{\lceil \log_2(PF) \rceil}$	Regular	PF	1; 0	$1/PT_s$
(A, m, VSL)	$2^{\lceil \log(_2 PF) \rceil}/PT_s$	$2^{\lceil \log(_2 PF) \rceil}$	Regular	PF	1; 0	$1/PT_s$
(B, m, MC, L)	$F\,2^{\lceil \log(_2 PL) \rceil}/PT_s$	$2^{\lceil \log(_2 PL) \rceil}$	Regular	PL	F; PT_s/F	$1/PT_s$
(B, m, VSL, L)	$F\,2^{\lceil \log_2(PL) \rceil}/PT_s$	$2^{\lceil \log_2(PL) \rceil}$	Regular	PL	F/m; PT_s/F	m/PT_s
(C, m, MC)	$F\,2^{\lceil \log_2 P \rceil}/PT_s$	$2^{\lceil \log_2 P \rceil}$	NOC	P	F; PT_s/F	$1/PT_s$
(C, m, VSL)	$F2^{\lceil \log_2 P \rceil}/PT_s$	$2^{\lceil \log_2 P \rceil}$	NOC	P	F/m; PT_s/F	m/PT_s

四、計畫成果自評

We developed a transceiver architecture of multi-rate OFDM-CDMA systems and showed its programmability such that the general system can operate under different scenarios with a common hardware structure and reconfigure by software implementation. Although our design focuses on multi-rate applications, this architecture is backward compatible to single rate OFDM-CDMA systems by setting m=1, to DS/CDMA systems by setting P=L=1 in MC-DS-CDMA mode, and to conventional OFDM systems by setting F=L=1 in single user case. Due to the occupied bandwidth of each OFDM-CDMA systems is kept fixed for users of any rate in both MC access and VSL access modes, multi-rate applications do not increase the requirement on some hardware devices, such as the sampling rate of A/D and the bandwidth of low-pass filter. The future work shall be analyzing the performance of each scenario and figuring out its relationship with these adjustable parameters such that optimal resource programming is realizable for future wireless multimedia applications.

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