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Title: Orthogonal Pilot Channel Structure in E-UTRA Uplink
Agenda Item: 5.2.2.2
Document for: Discussion and Decision

1. Introduction

We proposed an orthogonal pilot channel structure associated with intra-Node B coordination such as intra-node B transmission timing control and orthogonal radio resource assignment for single-carrier (SC)-FDMA based radio access in the Evolved UTRA uplink [1]. In the contribution, we presented that orthogonal channel generation using the frequency domain (FDM) and code domain (CDM) is more promising than using the time domain (TDM). This paper proposes the actual orthogonal physical channel generation method for SC-FDMA radio access in the E-UTRA uplink. The proposed orthogonal channel generation employs a combination of FDM and CDM.

2. Proposed Generation Method for Orthogonal Pilot Channel

In the paper, we focus on the orthogonality among UEs in all cells within the same Node B, i.e., all sectors. Here, we assume that the OFDM symbol timings of all cells in the same Node B are synchronized perfectly and the uplink transmission frame timing is generated based on the downlink received frame timing. Moreover, adaptive transmission timing controls among simultaneously accessing UEs are performed over all cells within the same Node B, so that the received timings of all UE in the same Node B are aligned within the CP (cyclic prefix) duration.

Figure 1 shows the proposed orthogonal pilot channel generation using the combination of FDM and CDM. The proposed method to multiplex orthogonal physical channels is as follows.

- **Multiplexing UEs with Different Transmission Bandwidths Using Distributed FDMA**

We use distributed FDMA in the frequency domain for multiplexing UEs with different transmission bandwidths. This is because orthogonality among UEs with different transmission bandwidths is not possible using CDM in general. However, FDMA can achieve orthogonality among UEs with different transmission bandwidths as shown in Fig. 1. Employing distributed transmission is necessary to obtain channel gain over the assigned transmission bandwidth.

- **Multiplexing UEs with Identical Transmission Bandwidth Using CDMA**

We use CDMA for multiplexing UEs with identical transmission bandwidths, i.e., sampling rates. In DS-CDMA, the code with a good auto-correlation property is necessary such as the CAZAC (Constant Amplitude Zero Auto-Correlation) sequence. However, the number of sequences is small when the CAZAC sequence is used as the pilot sequence, since the scrambling code cannot be used in conjunction with the CAZAC sequence. Thus, [2] proposed employing a cyclic shift based CAZAC code generation method, in which, multiple CAZAC sequences are generated by cyclic shift of the original CAZAC sequence. It was reported in [2] that the cyclic shift based CAZAC sequences provide a good cross-correlation property to mitigate mutual interference within the duration of the cyclic shift value. The cyclic shift value, Δ, is set so that it supports the maximum path delay time. We use the cyclic shift based CAZAC sequences from the one original CAZAC sequence with priority as shown in Fig. 2. Thus, when all cyclic shift based CAZAC sequences from the one original sequence are used up, we use the cyclic shift based CAZAC sequences from the second sequence.

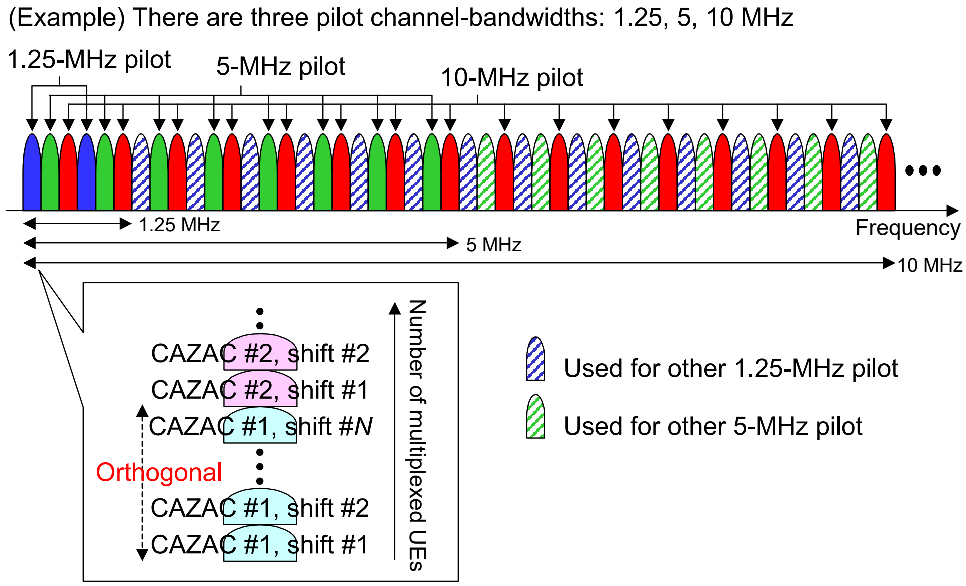


Figure 1 – Proposed orthogonal pilot channel generation using combination of FDM and CDM

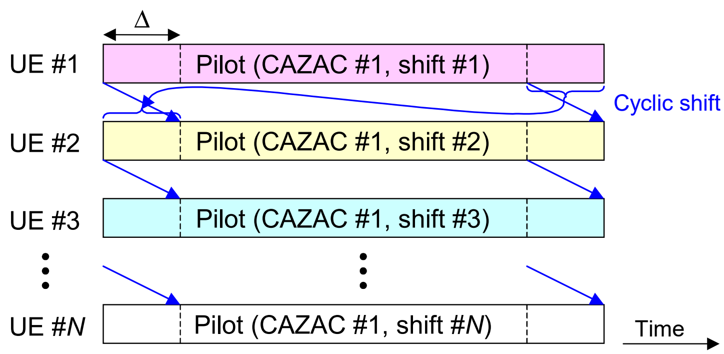


Figure 2 – Cyclic shift based CAZAC sequence generation from one original CAZAC sequence

Thus, by combining FDM and CDM multiplexing, orthogonality among UEs with different and identical transmission bandwidths is flexibly achieved. When distributed FDMA transmission is used, the sequence length of the pilot channel becomes short in the time domain. Thus, in the proposed method, we restrict the application of distributed FDMA only to UEs with different transmission bandwidths. Accordingly, we can accommodate a large number of cyclic shift based CAZAC sequences. Note that when all the available radio resources for orthogonality are used in the respective environments, we further allow non-orthogonal channel assignment.

3. Maximum Number of Orthogonal Channels in FDM

In this section, we investigate the maximum number of orthogonal channels, N_{mux}, in FDM. Assuming a TDM-base pilot channel structure, let Δf_{pilot} and Δf be the sub-carrier spacing in one pilot channel with FDM and the minimum sub-carrier spacing, i.e., 30 kHz, respectively. Then, Δf_{pilot} becomes Δf x N_{mux}. Thus, the relation such that $1 / \Delta f_{pilot}$ > largest delay time must be satisfied. We employ Greenstein's r.m.s. delay spread model in which τ_{rms} is represented as T_1 x d^{ε} x y (µsec) [6]. Then, the r.m.s. delay spread value at the cumulative distribution function (CDF) of 90 and 95% are calculated as shown in Table 1 for the inter site distance (ISD) of 2.8 and 5.0 km. From the r.m.s. delay spread values in Table 1, we calculated the largest delay time as listed in Table 2. Here, we assume an exponentially-decayed power delay profile model such as $p(t) = 1 / \tau_{rms}$ x $\exp(-t / \tau_{rms})$. We define the largest delay time as the delay time of the path, which is 10-dB decayed from the path energy of the greatest path, since approximately 90% of the total received power is collected. Therefore, we see from Table 2 that the largest delay time at the 90% CDF with σ_y = 2 dB case is approximately 4.2 and 5.6 µsec for the ISD of 2.8 and 5.0 km, respectively.

Table 1 – Delay spread

CDF	ISD = 2.8 km		ISD = 5 km	
	σ_y = 2 dB	σ_y = 5 dB	σ_y = 2 dB	σ_y = 5 dB
90%	1.8 µsec	4.3 µsec	2.4 µsec	5.7 µsec
95%	2.2 µsec	6.5 µsec	2.9 µsec	8.7 µsec

Table 2 – Largest delay time

CDF	ISD = 2.8 km		ISD = 5 km	
	σ_y = 2 dB	σ_y = 5 dB	σ_y = 2 dB	σ_y = 5 dB
90%	4.2 µsec	10.0 µsec	5.6 µsec	13.2 µsec
95%	5.2 µsec	15.1 µsec	6.8 µsec	20.1 µsec

Meanwhile, when N_{mux} is 1, 2, 3, 4, 5, 6, 7, and 8, the value of $1 / \Delta f_{pilot}$ becomes 33.3, 16.7, 11.1, 8.33, 6.67, 5.55, 4.76, and 4.17 µsec, respectively. Thus, we see for supporting the largest delay time for the ISD of 2.8 and 5.0 km, the allowable N_{mux} value becomes approximately four. Here, when we use staggered pilot symbol mapping of the FDM-based orthogonal pilot between two pilot blocks within the same sub-frame [1], [3] as shown in Fig. 3, we can increase the allowable N_{mux} value to twice equivalently. Consequently, we see that we can accommodate eight FDM-based orthogonal pilot channels in the environment with the ISD of up to approximately 5 km. However, eight orthogonal channels with FDM represents almost the worst case. Thus, it should be noted that a larger number of physical channels is multiplexed in FDM for UEs in the environments with shorter largest delay times.

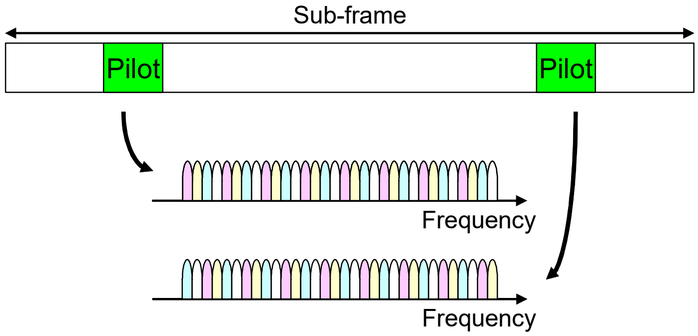


Figure 3 – Channel estimation using interpolation of orthogonal pilot channels employing distributed FDMA (Different comb-spectra are assigned to two pilot blocks)

4. Investigation on Pilot Sequence

We compare the average PER performance using the CAZAC sequence and random sequence in the pilot channel. Table 3 lists the simulation parameters, which follow the agreed parameters in [4]. The transmission bandwidth is 5 MHz. We use the Zadoff-Chu sequence [5] for the CAZAC sequence with the length of 151, along with a random sequence with the length of 150. We employ turbo coding with the coding rate of $R = 1/2$. We assume ideal FFT timing detection and ideal noise power estimation for the frequency domain equalizer. The channel gain is estimated in the time domain by taking the correlation within the pre-decided time window duration between the received signal and the pilot sequence replica. The sample points, which provide greater received power than the pre-determined threshold value, are selected within the time window in order to reduce the influence of the noise and interference. Thus, the correlations of the selected sample points are converted into a frequency domain signal by FFT. We employ a frequency domain equalizer employing the LMMSE algorithm, associated with two-branch antenna diversity reception.

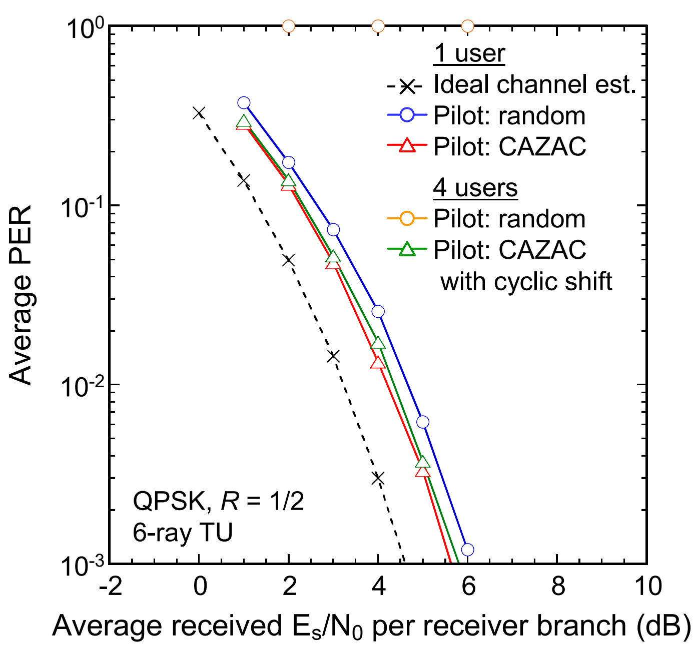
Table 3 – Simulation parameters

Transmission scheme	Localized FDMA
Transmission bandwidth	5 MHz
Sampling rate	7.68 Msps
Sub-frame length	0.5 msec (data block x 6, pilot block x 2)
Data block size	66.67 μsec / 512 samples
Pilot block size	33.33 μsec / 256 samples
Sub-carrier spacing	15 kHz (data blocks), 30 kHz (pilot blocks)
Pilot sequence	CAZAC (Zadoff-Chu) seq., Random seq.
Cyclic prefix duration	4.04 μsec / 31 samples
Time windowing	Raised cosine with 3.13 μsec / 24 samples
Data modulation	QPSK, 16QAM
Channel coding	Turbo coding (K = 4, R = 1/2)
Number of users	1, 4 users
Receiver	2-branch receiver reception, LMMSE frequency domain equalizer
Channel model	6-ray Typical Urban, Vehicular A

Figures 4(a) and 4(b) show a comparison of the average PER performance between the CAZAC and random sequences for QPSK and 16QAM modulations, respectively, as a function of the average received signal energy per symbol-to-noise power spectrum density ratio (E_s/N_0) per receiver branch. We use a six-ray Typical Urban (TU) channel model with the fading maximum Doppler frequency of f_D = 55.5 Hz (30 km/h at a 2-GHz carrier frequency). The number of simultaneous accessing UEs is set to one and four. The PER performance assuming ideal channel estimation is also given as a reference. In a four-user environment, we apply different CAZAC sequences, which are generated by cyclic shift of the original CAZAC sequence [2].

Clear improvements are observed in the CAZAC sequence compared to the random sequence. First, the results in a one-user environment show that the required average received E_s/N_0 per receiver branch for the average PER of 10^{-2} using the CAZAC sequence is reduced by approximately 0.5 dB compared to that of the random sequence for QPSK modulation. Furthermore, as shown in the Fig. 4(b), although the average PER of 10^{-2} is not achieved with the random sequence, it is significantly improved by the CAZAC sequence for 16QAM modulation. This is because the accuracy of the path timing detection and channel estimation is remarkably improved due to the good auto-correlation property of the CAZAC sequence.

Next, looking at the PER performance in the four-user environment, we find a clear benefit to the CAZAC sequence with cyclic shift compared to the random sequence. The average PER performance using the CAZAC sequence with cyclic shift in the four-user environment becomes almost identical to that in the one-user case. This is caused by the good cross-correlation property of the CAZAC sequences through cyclic shift based generation.



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