3GPP TSG RAN WG1 Ad Hoc on LTE **R1-051062**
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Source: **Texas Instruments**
Title: **On Uplink Pilot in EUTRA SC-FDMA**
Agenda Item: **8.2**
Document for: **Discussion/Decision**

1. Introduction

1.1 Problem Formulation

One of the two possible TTI structures for uplink Single Carrier FDMA (SC-FDMA), as proposed by drafting group 1, is given in Figure 1 below.

Figure 1: Uplink TTI structure for SC-FDMA.

In Figure 1, LB represents a "Long Block," which can contain only data symbols, and SB represents a "Short Block," which can contain either pilot or data symbols. Therefore, the uplink pilot is always confined inside the SB field. The time duration of the SB field is half of the time duration of the LB field. The rest of the numerology for the uplink frame structure is given in [1].

The proposed uplink TTI structure results in the frequency set where the width of pilot subcarriers is twice the width of data subcarriers. For example, in the baseline case of 5MHz bandwidth, pilot and data subcarriers are as given in Figure 2 below.

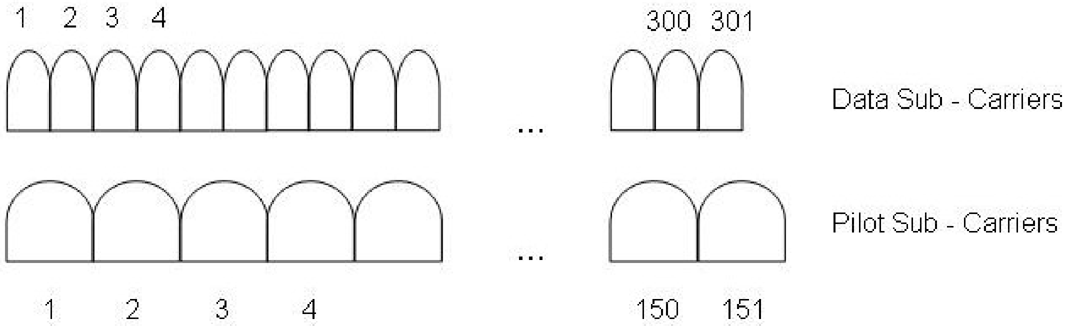


Figure 2: Frequency Set for SC-OFDM.

In the case of distributed (IFDMA) uplink transmission, each mobile is allocated a set of non-contiguous tones for data subcarriers. In this case, it is unclear as to which is the most appropriate allocation of uplink pilot resources. Furthermore, a relatively wide-band pilot may have benefits even for localized data transmission, because it enables frequency-dependent UE scheduling. The following options should be considered.

1.2 Possible Allocations for Orthogonal Uplink Pilot

a) Time Domain Orthogonality

Time domain orthogonality is the most obvious alternative for usage of the SB field for pilot transmission. However, such a solution may result in a high peak to average ratio (PAR) for uplink transmission, which would consequently decrease

b) Frequency Domain Orthogonality
Frequency domain (IFDMA) orthogonality is another proposed solution [3] for the uplink orthogonal pilot, which is a topic of current studies. The main difficulty faced by a frequency domain orthogonal pilot is for UE's near the cell border, when the neighbouring cell utilizes the same IFDMA uplink pilot channel. In such cases, UEs are likely to have a "dominant interferer" present. Dominant interferer, which resides in the neighbouring cell, significantly degrades channel estimation performance (for IFDMA pilot), even if his/hers signal is substantially attenuated. This claim will be demonstrated below using link – level simulations.

c) Code Domain Orthogonality
Code domain orthogonality can be achieved with a use of Constant Amplitude Zero Autocorrelation (CAZAC) sequences, as we demonstrate in the remainder of this document. Furthermore, CAZAC sequences have a flat frequency domain response, which makes them attractive for SC – OFDMA systems. Finally, CAZAC pilot is very robust to out-of-cell interference, which we show via link – level simulations.

In this contribution, we first demonstrate how to achieve pilot orthogonality in the code domain, via cyclic shifts of CAZAC sequences. Second, we demonstrate some of its advantages with respect to an alternate proposed solution of IFDMA pilot [3]

1.3 Background on CAZAC Sequences

An example of CAZAC sequences is given as follows. Let L be any positive integer, and let k be any number which is relatively prime with L. Then the n-th entry of the k-th Zadoff-Chu CAZAC sequence [2] is given as follows:

$$c_k(n) = \exp\left[\frac{j2\pi k}{L}\left(n + n\frac{n+1}{2}\right)\right] \qquad \text{if L is odd}$$

$$c_k(n) = \exp\left[\frac{j2\pi k}{L}\left(n + \frac{n^2}{2}\right)\right] \qquad \text{if L is even}$$

The set of Zadoff-Chu CAZAC sequences has the following properties:

- Constant magnitude
- Zero circular autocorrelation
- Flat frequency domain response
- Circular cross-correlation between two sequences is low and it has constant magnitude, provided that L is a prime number.

2. Proposal: Allocation of Uplink Pilot Sub-Channels

In this section we demonstrate how to achieve the uplink orthogonal pilot in the code domain with the use of CAZAC sequences. The main idea is to use a single CAZAC sequence per sector and exploit the property of zero circular autocorrelation along with the cyclic prefix transmission.

2.1 Allocation of Pilot Sub-Channels for a Single Sector

In order to illustrate how to achieve orthogonality in the code domain, we let the CAZAC sequence be "c," and let its right cyclic shift by Q be specified as $S_Q(c)$. Since the sequence has zero cyclic autocorrelation, then $S_0(c)$, $S_Q(c)$, $S_{2Q}(c)$ … $S_{MQ}(c)$ are all orthogonal provided that MQ does not exceed the length of the sequence. Furthermore orthogonal to the rest of $S_Q(c)$, $S_{2Q}(c)$ … $S_{MQ}(c)$. Next, we simply allocate $S_0(c)$ to be the pilot sequence for UE#0, $S_Q(c)$ to be the pilot sequence for UE#1, and proceed accordingly until we allocate $S_{MQ}(c)$ to be the pilot sequence for UE#M. Such an allocation is illustrated in the following figure.

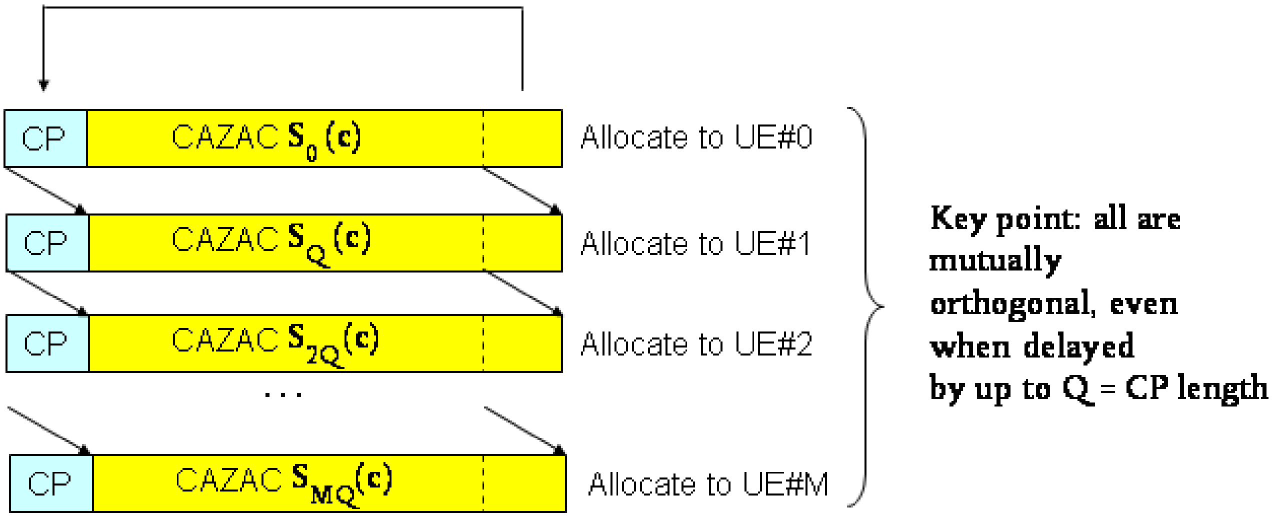


Figure 3: Proposed Allocation of Uplink Pilot Sequences.

With such an allocation, the arriving multipath signal from each UE will be orthogonal, under the assumption that Q is longer than each delay profile. For this reason an appropriate choice for Q is the prefix length of the transmission. Alternatively, a more conservative allocation would accommodate scenarios where the delay profile is longer than the prefix length. In such cases, Q should be longer than the transmission prefix.

2.2 Allocation of Pilot Sub-Channels in Softer Handover

For UE's which are in the Softer Handover, the transmitted signal is received with significant power level in two sectors of the Node B. In order to avoid UE self-interference, we propose that both serving sectors allocate the same CAZAC sequence, with the exact same shift, to UE's which are shared in the Softer Handover. Hence, each sector of a single Node B will utilize the same CAZAC sequence.

2.3 Allocation of Pilot Sub-Channels between different Node B's

Neighboring Node B's should utilize different CAZAC sequences for the uplink pilot channel in order to achieve interference averaging. For this reason, the most appropriate choice for CAZAC sequences are Zadoff-Chu sequences of prime length (see Background section above), which have low constant magnitude cyclic cross-correlation. Since the number of different Zadoff-Chu sequences is close to the length of the sequence itself (hence large), there are no difficulties in constructing the reuse pattern for distant Node B's.

2.4 Number of CAZAC sequences

As stated earlier in the background section, Zadoff – Chu sequences have low constant magnitude cross – correlation, provided that their length is a prime number. In this section, we present the number of possible sequences, assuming the exact uplink numerology from [1], Option2

Table 1: Number of CAZAC Sequences

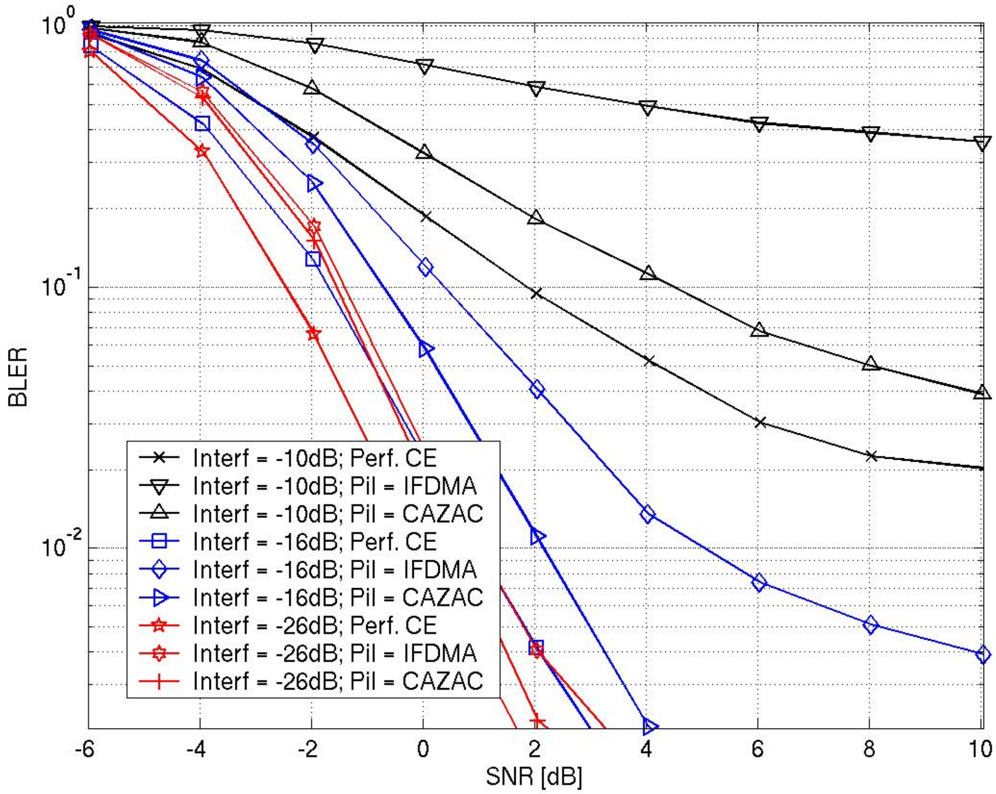
	1.25MHz	2.5MHz	5MHz	10MHz	15MHz	20MHz
LB Samples	128	256	512	1024	1536	2048
Used Subcarriers in LB	76	151	301	601	901	1201
SB Samples	64	128	256	512	768	1024
Used Subcarriers in SB	37	73	151	293	449	601
CP Samples	7	15	31	63	95	127
# of distinct CAZACs not including shifts	36	72	150	292	448	600
# of distinct CAZACs including 8 shifts	288	576	1200	2336	3584	4800

Table 1 is derived as follows. Rows 2 and 4 are from the uplink proposal in [1], Option2. Row 3 hasn't been agreed upon yet (for the uplink), which is why we assumed the downlink numerology from [1]. Row 5 is proposed to be the prime number which is closest to half of the Row 3. Row 6 is directly from [1]. Row 7 is derived based of properties (see background section) of Zadoff – Chu sequences. Finally, Row 8 is 8 * Row 7, since the SB (Row 4) accepts 8 distinct circular shifts by the cyclic prefix (Row 6).

2.5 Link – Level Simulation Comparison of IFDMA and CAZAC pilot: Dominant Interferer Present

Table 2: Simulation Assumptions

Parameter		Assumption
Bandwidth		5 MHz (2.6 GHz)
Channel Model		TU, Velocities: 3kmh, 120kmh, 360kmh.
Data Channel Turbo Coding		Rate ½
Data Modulation		16QAM
Uplink Numerology		Option 2 in [1] (Table 9.1.1.2)
Dominant out–of–cell interferer		C/I = 10dB, 16dB, 26dB.
Data Channel		Distr. FDMA which occupies each 6th tone. Number of Sub-carriers = 48. Dominant interferer uses same channel in neighboring cell
Antenna Configuration		1 at Transmitter, 2 at Receiver
Pilot	CAZAC	Dominant interferer from the neighboring cell uses different CAZAC (length = 151)
	Distributed FDMA which occupies each 6th tone. Number of Sub-carriers = 24	Dominant interferer from the neighboring cell uses same IFDMA pilot channel, with different pilot sequence
Pilot Modulation		QPSK
Channel Estimation	Time Interpolation	Doppler dependent filter coefficients MF – Wiener Matched Filter ZF – Wiener Zero Forcing Filter
	Frequency Interpolation	Least Squares
	Interpolation Method	Past, Current and Future TTI



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