Bit Error Rates of Large Area Synchronous Systems in the Presence of Adjacent Cell Interference

Gregory Cresp[1], *Hans-Jürgen Zepernick*[2], *Hai Huyen Dam*[3]

[1]School of Electrical, Electronic and Computer Engineering, The University of Western Australia
35 Stirling Hwy, Crawley, 6009, Australia, E-mail: crespg@watri.org.au

[2]Radio Communications Group, Blekinge Institute of Technology
PO Box 520, SE–372 25 Ronneby, Sweden, E-mail: hans-jurgen.zepernick@bth.se

[3]Department of Mathematics and Statistics, Curtin University of Technology
Perth 6102, Australia, E-mail: H.Dam@curtin.edu.au

Abstract

Large Area Synchronous (LAS) sequences are a class of ternary interference free window spreading sequences. One of their advantages is the ability to construct permutation LAS families in order to reduce adjacent cell interference in cellular systems. There has been little previous numerical work to examine the effect of using permutation families compared to simply reusing the same LAS family across different cells. The bit error rates resulting from two cell systems employing both permutation families and sequence reuse are considered here by simulation.

1. Introduction

Large Area Synchronous (LAS) sequences are a class of sequences originally proposed for third generation mobile telephony [1]. They are based on the combination of Large Area (LA) [2] and LS sequences [3], and aim to preserve the benefits, but mitigate the disadvantages, of both. One particular benefit is the construction of permutation families. When permutation sequences are used in a cellular system, adjacent cells need not reuse the same family [1, 4], potentially reducing adjacent cell interference (ACI). Previous work has made this claim of reduced ACI, but very little numerical testing has been performed. The correlation values of permutation LA families has been considered [4], as has the BER performance of non-permutation LAS families [5, 6]. However, the change in BER when using permutation families in a cellular system, compared to using sequence reuse, has not been examined.

In early work it was only possible to consider BER results through upper and lower bounds or through approximate models. With advances in computing power it is now also possible to evaluate performance through simulation [7]. By simulating the transmission of a large number of random data symbols over a modelled wireless channel, the BERs of different schemes can be compared. Such a simulation is preformed here to examine the performance of permutation and non-permutation LAS systems.

This paper is structured as follows. Section 2 introduces LAS and permutation LAS families. Section 3 introduces the simulation scheme used. In Section 4 the parameters of the simulations performed here, and the resulting BERs, are given. Section 5 concludes the paper.

2. LAS Families

An interference free window (IFW) family is a set of spreading sequences where the autocorrelations of any sequence and the cross-correlations between any two sequences are zero at shifts less than or equal to some integral number of chips, W. The value W is referred to as the radius of the IFW. If the maximum inter-user delay is less than W chips, then multiple access interference (MAI) is eliminated from the system.

LA and LS families are both classes of ternary IFW families. LA families were originally defined in [2]. The construction used here is described in detail in [8]. The structure of the LS family is as described in [3]. These families are combined via absolute encoding [9] to produce an LAS family. An LAS family is also ternary and exhibits an IFW of the same radius as the component LS family. Multiple permutation LAS families can be produced from an LAS family. This is analogous to the construction of permutation LA families [4], and is as used in the LAS2000

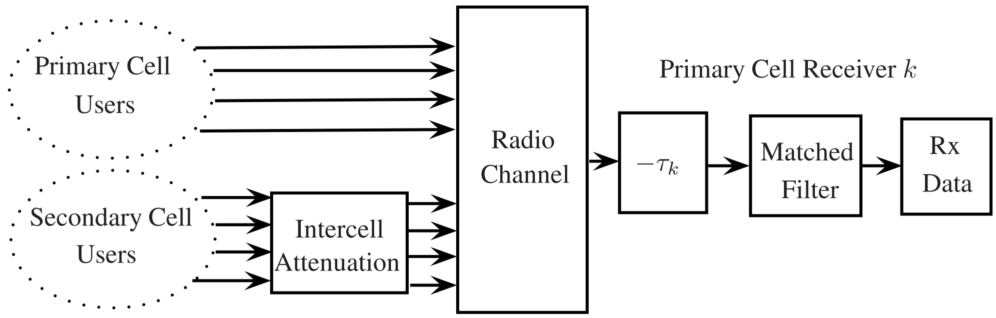


Figure 1: A block diagram of the LAS system used to calculate BERs, based on [7].

proposal [1]. In a permutation family the spacings between copies of the component LS sequences are reordered according to some permutation.

3. System Model for Bit Error Rate Simulation

The BERs considered here are produced from the uplink channel of a simplified two cell, discrete, baseband simulation environment. The system considers two adjacent cells, referred to respectively as the primary and secondary cells. The primary cell employs the sequence family $\mathcal{U}$, the secondary cell employs the family $\mathcal{V}$. In a sequence reuse system both families are the same, whereas in a permutation system $\mathcal{V}$ is a permutation family based on $\mathcal{U}$.

3.1. Simulating the Transmitter and Receiver

A block diagram of the system used is shown in Figure 1. The transmission model for users is the same across both cells. For a given simulation, each user transmits D bits of user data. This data is first converted into quadrature phase shift key (QPSK) symbols. These symbols are spread by the user's spreading sequence. The same sequence is used to spread the in-phase and quadrature components of the symbol.

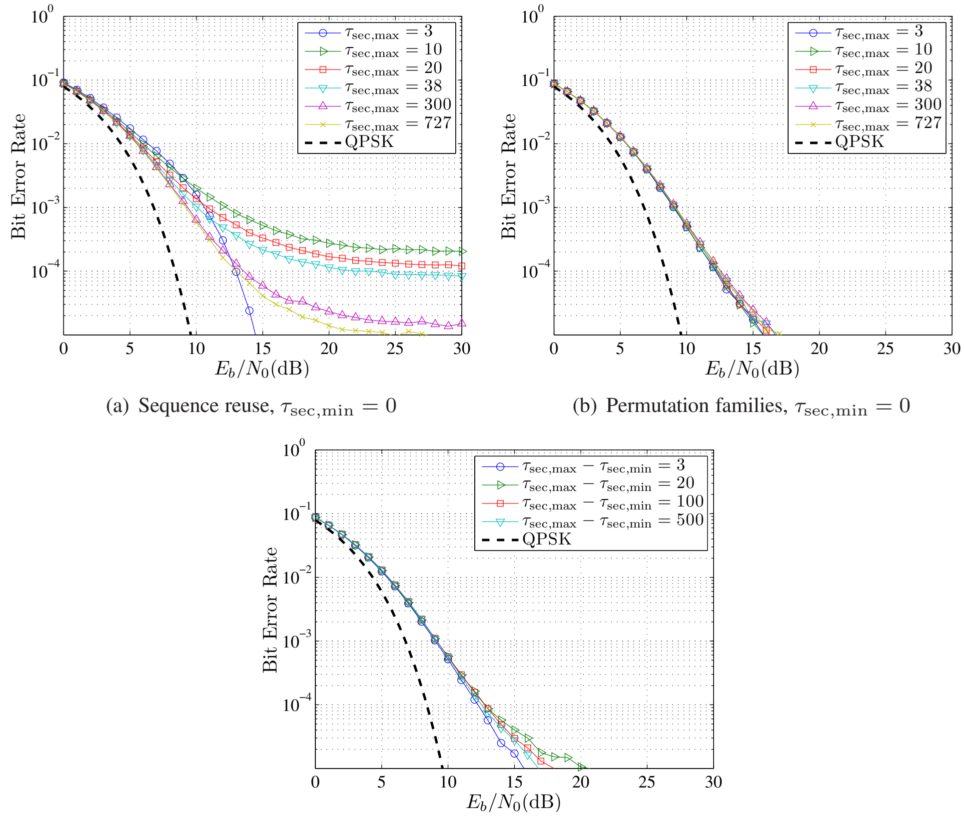
To simulate shifts between the arrival of different users' signals, each user's signal is delayed by a random amount. Since IFW families are intended for use in quasi-synchronous systems, these delays are bounded. The k^{th} primary cell user is delayed by τ_k chips, where $0 \leq \tau_k \leq \tau_{\max}$. The r^{th} secondary cell user is delayed by $\tau_{\mathrm{sec},r}$ chips, where $\tau_{\mathrm{sec,min}} \leq \tau_{\mathrm{sec},r} \leq \tau_{\mathrm{sec,max}}$. The values τ_k and $\tau_{\mathrm{sec},r}$ are all independent and uniformly distributed between their minimum and maximum values. Noting that the level of MAI and ACI will vary with these delays, a large number of delay sets are generated, and the BER simulation performed for each. The final BER is the average of these values over all simulations.

The delayed signals are combined in an additive white Gaussian noise (AWGN) channel. The output of this channel is considered at the primary cell's receiver, attempting to receive each user's signal in turn. The signal to noise ratio (SNR) relative to the desired primary cell signal is E_b/N_0. The interfering signals from the other primary cell users are all assumed to arrive at the same power as the desired signal. Noting the physical separation between the primary and secondary cells, signals from the secondary cell arrive at the receiver with a power 3dB lower than the primary cell signals.

The received signal is first synchronised to the required user by imposing a delay of $-\tau_k$ chips. In practice, achieving synchronisation would require sufficient autocorrelation performance, or the use of an external pilot signal. The user data is then extracted via a filter matched to the user's spreading sequence.

3.2. Simulation Scenarios

Two scenarios are considered here for the secondary cell. First, it is assumed that signals from the secondary cell can arrive synchronously with the primary cell signals, that is that the minimum secondary cell delay is $\tau_{\mathrm{sec,min}} = 0$.



(a) Sequence reuse, $\tau_{\text{sec,min}} = 0$

(b) Permutation families, $\tau_{\text{sec,min}} = 0$

(c) Sequence Reuse, $\tau_{\text{sec,min}} = 10$

Figure 2: BER for the LAS systems in the first scenario ($\tau_{\text{sec,min}} = 0$) and the second scenario ($\tau_{\text{sec,min}} = 10$).

Whilst transmission within the secondary cell will be roughly synchronised, the physical separation between the cells may result in the signals' arrival at the primary cell being widely spread. This is considered through a range of values for the maximum delay, $\tau_{\text{sec,max}}$.

In the second case, it is assumed that the physical separation between the cells and differences in the synchronisation reference result in it being impossible for the primary and secondary cell signals to arrive at the receiver simultaneously. This corresponds to $\tau_{\text{sec,min}} > \tau_{\max}$. As in the first scenario, different ranges of secondary cell delays are examined by considering a range of values for $\tau_{\text{sec,max}} - \tau_{\text{sec,min}}$.

4. Numerical Results

In all systems here the primary cell's sequence family, $\mathcal{U}$, is a $(728, 38, 16) \times (4, 4, 3)$ LAS family. It contains $16 \times 2 \times 4 = 128$ sequences, each of length 728. The component LA family contains 16 sequences, with a minimum spacing between pulses of 38. The set of pulse spacings used to construct the LA family is

$$\{d_j\}_{j=0}^{15} = \{38, 39, 40, 41, 42, 43, 46, 44, 47, 49, 45, 53, 52, 48, 51, 50\}. \tag{1}$$

The component LS family contains $2 \times 4 = 8$ sequences, each of length $2(4 \times 4 + 3) = 38$. These LS sequences are constructed from Golay pairs of length 4, using 8 Golay sequences per LS sequence and zero gaps of width 3. Where permutation sequences are used, the permutation reverses the order of the elements $1, 2, \ldots, 16$.

The maximum relative delay between primary cell users is taken to be $\tau_{\max} = 3$ for every simulation. Noting the IFW radius of $\mathcal{U}$ is $W = 3$, this ensures that the primary cell always operates within the IFW, and hence there is no MAI within the primary cell. The only source of interference is ACI from the secondary cell. As a result, the second scenario, where signals from the two cells cannot arrive synchronously, corresponds to a minimum delay of $\tau_{\mathrm{sec,min}} > 3$. The value $\tau_{\mathrm{sec,min}} = 10$ is used, although very similar BERs were observed for different choices.

Consider the first scenario, where it is possible for signals from the two cells to arrive at the receiver synchronously. The resulting BERs are shown in Figures 2(a) and 2(b), for the sequence reuse and permutation systems, respectively. The BER for the sequence reuse case, initially high when the range of delays from the secondary cell is low but reducing as this range increases, is symptomatic of the ACI behaviour. Noting that delays are uniformly distributed, if the range of delays is small then the probability of a secondary cell sequence arriving synchronously with its primary cell counterpart is high. These two signals cannot be distinguished, so this corresponds to a high level of interference. As the range of delays of the secondary cell signals increases, the probability of this synchronous arrival decreases, and thus so does the corresponding ACI and hence BER. In contrast, when permutation families are used there is no such reuse of sequences. The resulting ACI is thus low, so the BER is correspondingly low. Figure 2(b) also demonstrates how little the level of ACI varies with the changing delay range.

Consider now the second scenario, where signals from the two cells cannot arrive synchronously. This change has a minimal impact on the permutation family system, the resulting BERs are the same as those shown in Figure 2(b). There is a large change to the sequence reuse system, the BER results in this case are seen in Figure 2(c). In this case the problematic synchronous arrival of two signals using the same sequence can no longer occur. This leads to much lower BERs, similar to those experienced in the permutation family system.

5. Conclusions

Claims have previously been made that the use of permutation LAS sequences can greatly reduce the ACI, and hence BER, of a cellular system, compared to LAS sequence reuse. However, numerical results have been limited to the correlation performance of permutation LA, or to the BERs of non-cellular systems. Here the BER results of a two cell system employing LAS sequences was considered. A system employing permutation families was compared to the system simply reusing the same family in both cells. It was shown that the performance of a sequence reuse system was highly dependent on the nature of the delays between the two cells. If the minimum delay between the cells was zero, i.e. signals from the cells can arrive at a receiver synchronously, the BER was heavily impacted compared to the permutation family case. This impact was reduced as the range of delays increased. However, if the delay between cells was sufficiently large that such a synchronous arrival was impossible, the performance of the two classes of system were similar, and hence there was less advantage gained from employing permutation families.

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