

PSSS-OFDM

P. I. M. Urriza

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Development, Characterization and Implementation of PSSS-OFDM

A Novel Physical Layer for Robust Wireless Communication Systems

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Electrical and Electronics Engineering Institute
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July 13, 2009

Overview of Presentation

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Parallel Sequence Spread Spectrum (PSSS)

PSSS-OFDM

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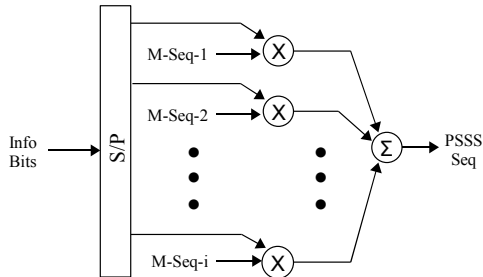
Summary of

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- Parallel DSSS operations
- Higher bitrates than DSSS
- Low complexity



PSSS Encoder

Orthogonal Frequency Division Multiplex (OFDM)

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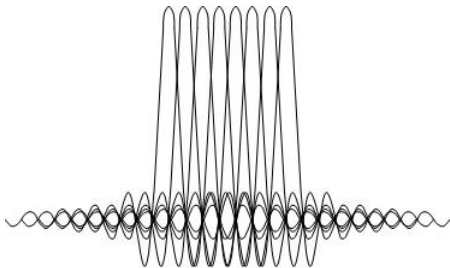
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- Uses multiple subcarriers which overlap and are orthogonal to each other
- Very robust against multipath fading
- Low complexity equalization
- Used in high data-rate, wideband communications



OFDM Subcarriers

Proposed Scheme

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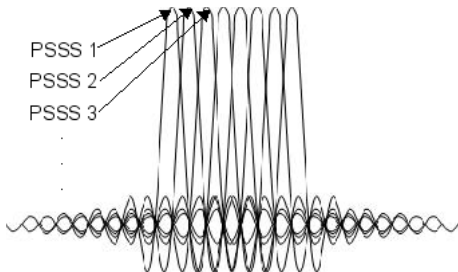


Illustration of the proposed scheme

PSSS-OFDM

- Each subcarrier carries a PSSS chip
- Provides additional multipath resistance to PSSS

Motivations

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- 1 Multipath robustness
- 2 Simpler equalization
- 3 Low complexity gain over standard OFDM
- 4 Flexibility in the amount of spreading

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- **H. Schwetlick and A. Wolf** PSSS - Parallel Sequence Spread Spectrum a Physical Layer for RF Communication. 2004.
- **IEEE Std 802.15.4-2006** Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs). 2006.
- **H. Schwetlick and A. Huhn** A simple time domain PSSS-MIMO for home networks. 2008.

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Multicarrier Spread Spectrum (MCSS)

Multicarrier DSSS

- **S. Kondo and B. Milstein** Performance of multicarrier DS CDMA systems. 1996.

Multicarrier CDMA

- **N. Yee, et.al.** Multi-Carrier CDMA in Indoor Wireless Radio Networks. 1993.

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Multicarrier Spread Spectrum (MCSS)

Multitone Spread Spectrum

- **L. Vandendorpe** Multitone spread spectrum multiple access communications system in a multipath Rician fading channel. 1995.

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Multicarrier Spread Spectrum (MCSS)

Frequency Diversity Spread Spectrum

- **G.K. Kaleh** Frequency-diversity spread-spectrum communication system to counter bandlimited Gaussian interference. 1996.
- **Z. Ye, et.al.** Anti-jam, anti-multipath spread spectrum OFDM system. 1998.

This Work

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PSSS-OFDM

- A variant multicarrier spread spectrum technique using PSSS as the spreading transform
- Based on MC-CDMA by N. Yee, et.al.
- Employs flexible spreading gain similar to RA-OFDM by Z. Ye, et.al.
- Spreading as opposed to repetition used by Kaleh
- Practical implementation

Objectives

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- 1 Design an integrated PSSS-OFDM scheme.
- 2 Verify its performance gains through simulation.
- 3 Develop a hardware architecture for the PSSS-OFDM scheme.
- 4 Characterize the system in terms of data-rate and logic utilization.

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General Parameters

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Hybrid 802.11a

Most OFDM parameters were adapted from the existing 802.11a (WLAN) standard:

- Bandwidth : 20 MHz
- # of data subcarriers : 48

PSSS Parameters

- M-sequence is length 15 (PSSS-15)
- 3 PSSS-15 sequences in one OFDM frame

General Parameters

PSSS-OFDM

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Precoding and Dynamic Thresholding

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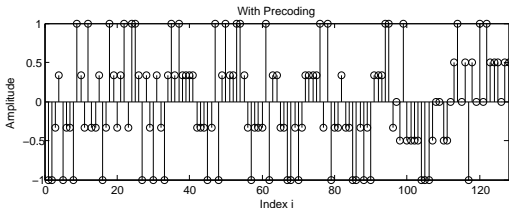
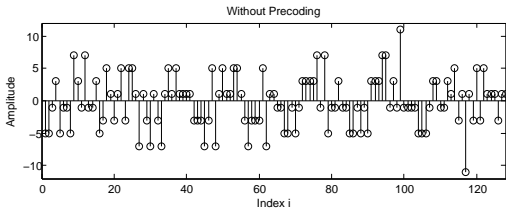
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Precoding Operation

$$p'(m) = p(m) - \frac{(\text{Max} + \text{Min})}{2} \quad p''(m) = \frac{p'(m)}{p'_{\max}}$$



Effect of Precoding in BER

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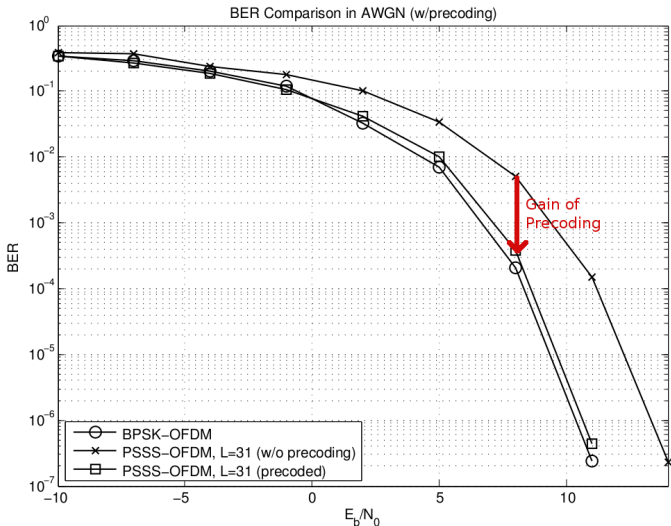
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Interleaving in the Frequency Domain

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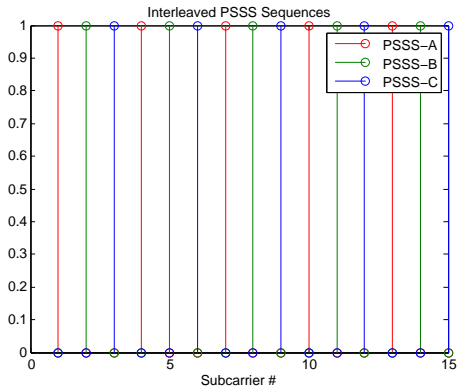
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Concept

PSSS samples are placed alternately in frequency.



Motivation

Fades in frequency are distributed over multiple sequences.

Variable Spreading

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- Achieved by not adding all cyclic shifts of the m-sequence
- Unused m-sequences are used for dynamic thresholding
- Results in various PSSS-OFDM modes

Note

Different PSSS-OFDM modes are identified by the number of bits contained in a single OFDM frame.
(i.e. PSSS-OFDM-31 means 31 bits are transmitted per OFDM frame)

Variable Spreading

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Final PSSS-OFDM Algorithm

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- 1 S/P to form 3 streams of data (+1/-1)
- 2 PSSS is applied using 15-chip m-sequence
- 3 Precoding
- 4 Interleaving
- 5 16-symbol cyclic prefix
- 6 Dynamic thresholding

Block Diagram of the PSSS-OFDM Transceiver

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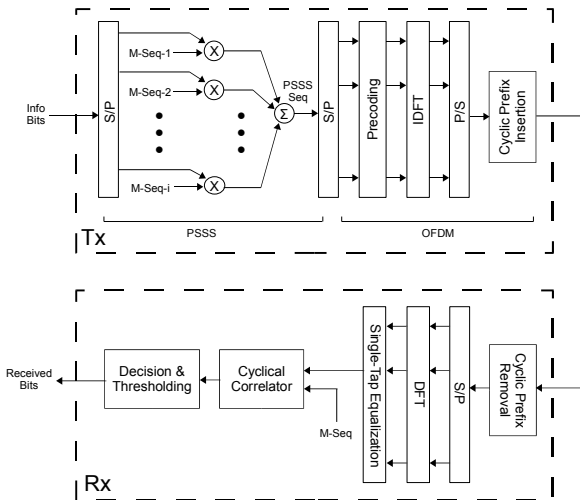
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Channel Model

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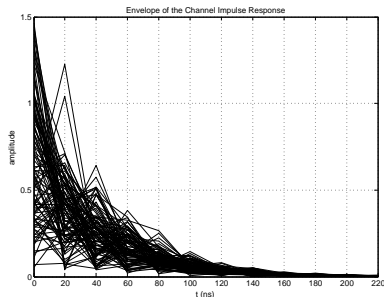
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Statistical Model for Frequency Selective Fading^a

$$h(t) = \sum_{n=1}^L B_n e^{j\theta_n} \delta(t - t_n)$$

^aA. Saleh and R. Valenzuela. A Statistical Model for Indoor Multipath Propagation. 1987.



Simulations were done using MATLAB

PSSS vs. PSSS-OFDM in Frequency Selective Fading

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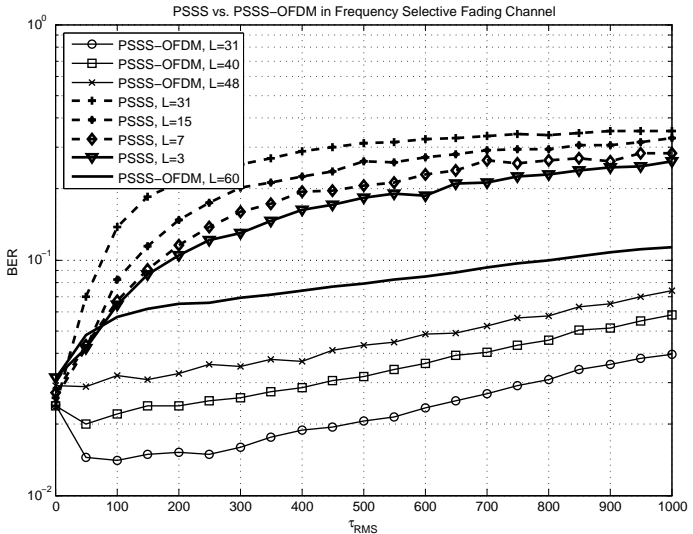
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OFDM vs. PSSS-OFDM in Frequency Selective

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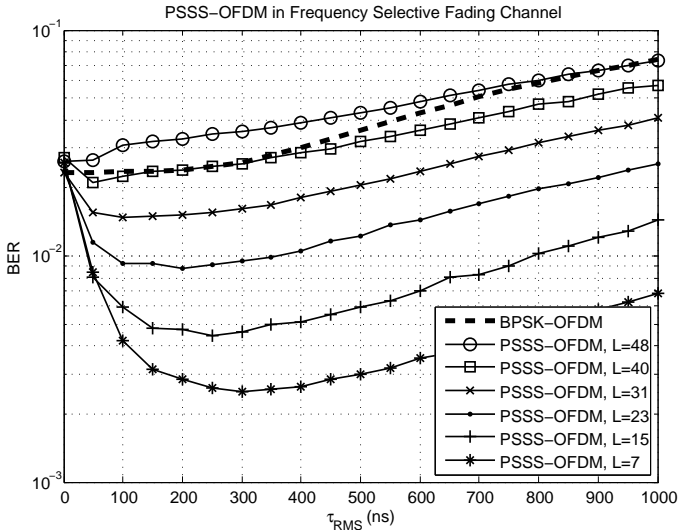
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Effect of Varying E_b/N_0

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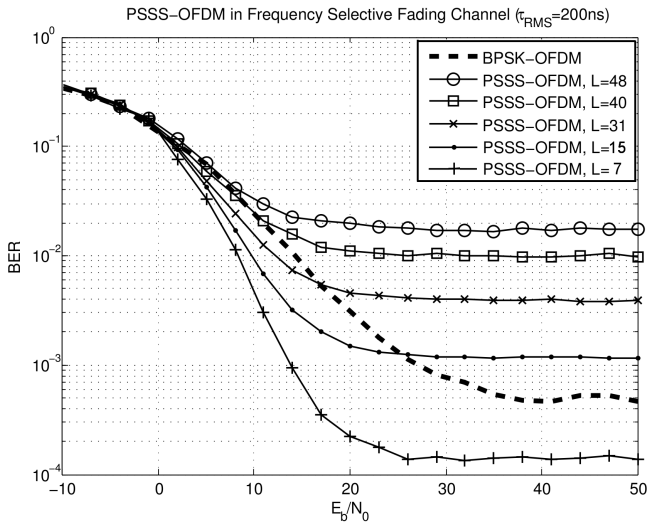
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Implementation Details

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- MATLAB Simulink + Xilinx System Generator for rapid prototyping
- Code used in simulation reused to test System Generator implementation
- Target: Xilinx Virtex 4 XC4VFX12

Parameter	Value
CLB Array	64 x 24
Number of Slices	5,472
Number of LUTs	10,944
Maximum Distributed RAM or Shift-registers	86
Number of Flip-Flops	10,944

Table: Specifications of the Xilinx Virtex 4 XC4VFX12 FPGA

Top-level block diagram of the PSSS Spreader

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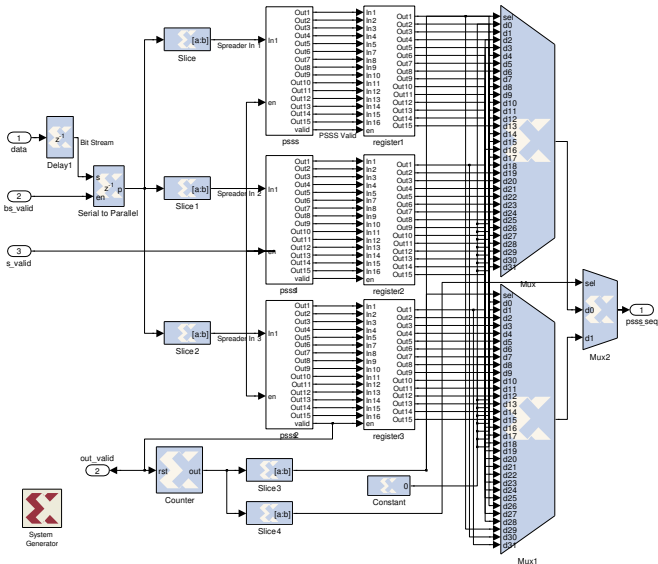
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Top-level block diagram of the PSSS Decoder

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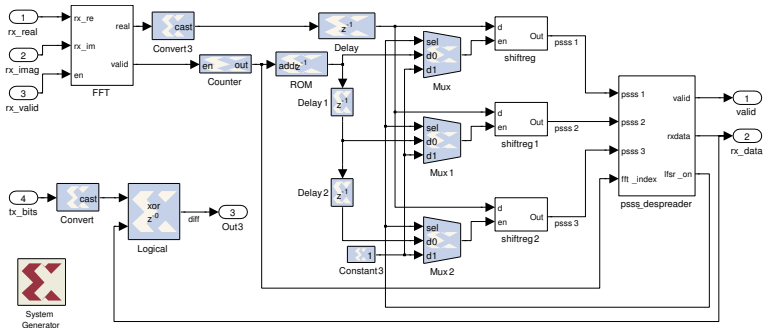
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Testing

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- Each block's output was compared to those generated by MATLAB scripts
- Hardware accurate simulation of PSSS-OFDM tranceiver in System Generator
- Text containing a poem¹ was transmitted and received accurately

¹Ode to Joy based on 802.11a Std Annex G

Logic Utilization - Transmitter

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Parameter	Value	Max	Percent
Slice Flip Flops	2,174	10,944	19%
4 input LUTs	1,886	10,944	17%
Occupied Slices	1,612	5,472	29%
FIFO16/RAMB16s	3	36	8%
DSP48s	6	32	18%

Table: Logic Utilization of the PSSS-OFDM Transmitter

Logic Utilization - Receiver

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Parameter	Value	Max	Percent
Slice Flip Flops	2,815	10,944	25%
4 input LUTs	2,450	10,944	22%
Occupied Slices	2,111	5,472	38%
FIFO16/RAMB16s	3	36	8%
DSP48s	6	32	18%

Table: Logic Utilization of the PSSS-OFDM Receiver

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A scheme incorporating PSSS and OFDM was successfully developed, characterized and implemented in a practical system.

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1 Incorporation of the PSSS algorithm with OFDM

- Variable frequency diversity gain
- Substantial improvement compared to PSSS
- Comparable in performance to OFDM at 50% spectral efficiency.
- Better multipath performance can also be achieved by using lower spectral efficiency modes.

2 Performance in various channel conditions

- Comparison to plain PSSS and plain OFDM.
- Simple single-tap phase equalization.
- Alternative scheme for WLANs.

3 Hardware implementation for PSSS-OFDM

- Use of Xilinx System Generator for rapid prototyping
- FPGA Target

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PSSS-OFDM

P. I. M. Urriza

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Thank you very much and God bless!

PSSS-OFDM

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Questions?