CoWare®

SPW 4–WLAN Library

HIGHLIGHTS

- **Accommodates the design of wireless networks and terminals, including network infrastructure, for home or business including headsets, cellular phones, digital cameras, and other personal electronic devices using IEEE802.11x, Bluetooth or UWB technology (See Figure 1)**
- **Includes a number of WLAN and WPAN system testbenches**
- **Enables fixed-point algorithmic design capture and datapath performance analysis**
- **Allows direct co-simulation of C (or C++) and HDL blocks using a single simulation process**
- **Designed for both systems and implementation (Hardware/Software) engineers**
- **Accelerates complete design of a 3G wireless personal device when used with other optional SPW libraries such as the SPW WCDMA library and Multimedia library**

Overview

SPW is an environment for the development of products based on IEEE802.11, IEEE802.11a, IEEE802.11b, IEEE802.11g, IEEE 802.11n and Bluetooth™ wireless technology, as well as the two proposals for Ultra Wide Band (UWB) standard in IEEE 802.15.3a task group, namely the MBOA and DS-UWB proposals.

The Wireless LAN library, implemented within SPW product, helps you design, implement, and verify the physical layer baseband of WLAN and WPAN systems. It can significantly reduce your development time and can increase your chance of first-time success. Throughout the datasheet we will refer to IEEE802.11, IEEE802.11a, IEEE802.11b, IEEE802.11g as IEEE802.11x for easier reading.

Figure 1. Examples of products and areas using 802.11x or Bluetooth Connectivity

The SPW Wireless LAN library contains both the basic blocks and the system models describing the IEEE802.11x WLAN, UWB and the Bluetooth wireless connectivity technologies. The IEEE802.11x library can be used to develop systems and ICs for building wireless networks. The UWB library can be used to develop systems and ICs for building high-bandwidth wireless solutions that are needed for applications such as wireless connections between digital camcorders and cameras, DVD players, TVs, and video games. The Bluetooth specification, although similar, can be used to design products such as personal electronic devices that connect to each other and to larger networks.

Using these libraries within the SPW environment accelerates the designer's process of embedded systems' algorithm optimization and algorithm implementation. The baseband design elements of a WLAN reference model can be integrated into a complete system model, a model which includes all aspects of the environment. Rapid simulation followed by signal analysis enables optimization of the system model. Performance optimization may result in a more valuable product that has higher bandwidth, lower error rates, greater communication range, better interference filters and/or has additional features valued by the end-user.

Benefits

- Rich set of blocks allows to quickly assemble designs for various WLAN and WPAN modems
- Reference systems for WLAN and WPAN standards help quickly verify the design
- Golden models accommodating all different environmental conditions can be used as a starting point for design implementation

Introduction

IEEE 802.11

The SPW IEEE 802.11 models are based on the 2.4 GHz band, direct sequence spread spectrum part of the IEEE 802.11 standard. Both 1Mbps and 2Mbps data rates can be simulated with the same system.

The transmitter generates the packets, modulates the symbols, and spreads them using a Barker code. Independent packets are sent at random intervals in time. Each packet contains the preamble, the header, and the media access control protocol data unit (MPDU) data.

The preamble contains the synchronization bits and the header contains the information about the data rate, the size of the MPDU data, and the CRC. Each packet is passed through a scrambler. The preamble and header parts of the packet are always modulated using differential BPSK and the data part is modulated using differential BPSK if the data rate is 1Mbps and using differential QPSK if the data rate is 2Mbps. The modulated signals are spread with 11-chip Barker code. Since there is no channel model specified in the 802.11 standard, the channel model used in the SPW 802.11demonstration system is based on the indoor channel model specified in the IMT2000 3G wireless standard.

The receiver performs both acquisition and data decoding. The acquisition part of the receiver uses a sliding correlator for signal despreading. Then the signals are correlated with the synchronization bits and the SFD (start frame delimiter) bits to check for the presence of a signal. These correlated values are sent to an FSM block for timing and delay estimations of three distinct signal propagation paths. The delay estimates are used in a three-finger rake receiver. Delay locked loop time tracking is used on each rake finger. The header of the frame is demodulated using differential BPSK from which the information about the data rate and the size of the data block are decoded. This information is used in the selection of differential BPSK or differential QPSK demodulation scheme for the data part of the packet. The packet will be dropped if the packet header fails the CRC error checking. After the packet header passes the CRC error checking the receiver demodulates the signal for the duration given in the packet header. During this period of time the receiver will not respond to any signal from the acquisition part.

The simulation creates two signal files: one containing the decoded bits from the received packets and the other containing the actual bits sent from the transmitter. The data in these files can be used for BER computations.

IEEE 802.11a

The SPW IEEE 802.11a models are based on the High speed Physical Layer standard defined over the 5 GHz band, which uses Orthogonal Frequency Division Modulation (OFDM) technology to provide data rates of 6 up to 54 Mbps.

The transmitter generates the Physical layer Service Data Unit (PSDU, i.e. data packets) and adds the Service, Tail and Pad bits to form the DATA field. The contents of Data field are then scrambled, using a length-127 PN sequence generator. The scrambled bits are encoded using a Convolutional encoder with coding rate R=1/2. Coding rates R=2/3 and R=3/4 are achieved by puncturing the encoder output. Encoded bits are interleaved and mapped to modulated symbols, using one of the following modulation schemes: BPSK, QPSK, 16-QAM and 64-QAM. Different data rates are achieved by combining different coding rates and modulation schemes. Modulated symbols are then mapped to OFDM subcarriers, along with the pilot symbols. Cyclic extension is applied to each OFDM symbol and a windowing function is applied to each OFDM symbol to smooth the transitions between consecutive symbols.

Physical Layer Convergence Procedure (PLCP) preamble and SIGNAL field are then added to the beginning of the data carrying OFDM symbols to form the PLCP Protocol Data Unit (PPDU) frame. PLCP preamble consists of ten short and two long training symbols, which are used for packet detection, coarse and fine frequency offset estimation, timing synchronization and channel estimation. SIGNAL field contains information on data rate of the transmitted packet as well as its length. The contents of this field are not scrambled, are encoded (R=1/2) and BPSK modulated.

The SPW IEEE 802.11a demo includes models for the following impairments: power amplifier (PA) non-linearity (based on Rapp model, which models amplitude-to-amplitude (AM/AM) distortion and assumes negligible amplitude-to-phase (AM/PM) distortion for solid-state amplifiers), oscillator phase noise, frequency offset between local oscillators at the transmitter and receiver, timing drift between sampling clocks at the transmitter and receiver, amplitude/phase/DC imbalance between I & Q branches of the received baseband complex signal, multipath fading channel and additive white Gaussian noise. The fading channel is modeled using a tapped delay line with exponentially decaying weights on the taps and independent Rayleigh fades on each tap. In addition, algorithms are included to reduce the Peak-to-Average-Power Ratio of the OFDM signal.

The receiver uses the short symbols in the PLCP preamble to detect the arrival of the packet, recover the timing and perform coarse and fine frequency offset estimation (fine estimation is done using the long symbols). The received OFDM waveform is then converted to frequency domain (using an FFT transform). Channel estimation and compensation is then performed using the long symbols in the PLCP preamble. The pilots embedded in OFDM symbols are used to correct the common phase error and the sampling clock drift. Rate and length of the received packet are detected using the SIGNAL field. This information is then used to demodulate, de-interleave, de-puncture and decode the received symbols (using a Viterbi decoder with either hard or soft decision decoding).The transmitted and received bits as well as symbols are then compared to compute the Block Error Rate (BLER) as well as the Error Vector Magnitude (EVM).

IEEE 802.11b

The SPW IEEE 802.11b model is based on the standard for higher speed physical layer extension in the 2.4 GHz band. It includes data rates of 1 and 2 Mbps using the physical layer (PHY) for Direct Sequence Spread Spectrum (DSSS) system defined in IEEE 802.11 Standard, as well as higher speed data rates of 5.5 and 11 Mbps using Complementary Code Keying (CCK) modulation scheme, also referred to as High Rate Direct Sequence Spread Spectrum (HR/DSSS). It does NOT include the optional mode of Packet Binary Convolutional Coding (PBCC).

The transmitter generates a complete packet (PPDU), which includes the PLCP preamble, PLCP header and the PSDU (with variable length). The resulting PPDU is then scrambled, modulated and spread before being sent over the channel. For 1 and 2 Mbps modes, DBPSK and DQPSK modulations are used, respectively and the resulting signal is spread using the length 11 Barker code. For 5.5 and 11 Mbps modes, CCK encoding is performed.

The multipath fading channel is same as the one used in IEEE 802.11a model. It is modeled using a tapped delay line with exponentially decaying weights on the taps and independent Rayleigh fades on each tap. The fading can be either fixed over the length of a packet or time varying with a given Doppler rate.

The receiver is an ideal receiver, where it assumes complete knowledge of the channel response and the timing of the received signal.

Channel compensation is performed by aligning the received signal and its delayed copies in time and combining them into one signal, using known path delays and gains. The resulting signal is then de-spread, demodulated and de-scrambled to detect the transmitted PSDU. For 1 and 2 Mbps modes, the received signal is de-spread using the length 11 Barker code and then demodulated using DBPSK and DQPSK demodulators, respectively. For 5.5 and 11 Mbps modes, CCK decoding is performed. The received CCK modulated packet is first correlated with all possible 256 vectors (16 for 5.5 Mbps) and the vector with maximum correlation is chosen, which is later demodulated to decode the transmitted bits. The transmitted and decoded bits are then compared and the resulting packet and bit error rates are recorded.

IEEE 802.11g

The SPW IEEE 802.11g model is based on the standard for further higher speed physical layer extension in the 2.4 GHz band. It includes the ERP-DSSS/CCK mode, which supports data rates of 1 and 2 Mbps using the physical layer (PHY) for DSSS system defined in IEEE 802.11 standard and data rates of 5.5 and 11 Mbps using CCK modulation scheme defined in IEEE 802.11b standard; and the ERP-OFDM mode, which supports data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps using OFDM technique defined in IEEE 802.11a standard. It does NOT include the optional ER-PBCC and DSSS-OFDM modes.

The transmitter combines the transmitters used for the IEEE 802.11a and IEEE 802.11b models, which are explained above. The fading channel is the same as the one used in IEEE 802.11a/b models and the receiver combines ideal receivers for IEEE 802.11a and IEEE 802.11b models, where it is assumed that the receiver has complete knowledge of timing and channel.

IEEE 802.11n

The SPW IEEE 802.11n library currently consists of only the channel model adopted by TGn task group. The IEEE 802.11n channel model augments SPW's WLAN library facilitating the early research of 802.11n performance in the standardization community. Leading semiconductor companies are already using pre-release versions of this channel model to upgrade their previous 802.11 designs for this higher performance option. SPW supports the full range of models for NLOS for small, large office configurations as well as open-space indoors and outdoors.

MBOA UWB Proposal

The SPW MBOA model is based on the Multi-Band Orthogonal Frequency Division Multiplexing (MB-OFDM) PHY proposal for UWB standard to IEEE 802.15 Task Group 3a by the MBOA consortium. The proposed system uses OFDM along with time-frequency codes to provide data rates of 55-480 Mbps over 3 frequency bands, each 528 MHz wide.

In the MBOA transmitter, data bits are first scrambled using a length-15 PN sequence generator. The scrambled bits are then encoded using a Convolutional encoder with coding rate of 1/3. Coding rates of 11/32, 1/2, 5/8, and 3/4 are achieved by puncturing the encoder output. Encoded bits are then interleaved in a block interleaver and mapped to modulated symbols, using QPSK modulation. Modulated symbols are then mapped to 100 OFDM subcarriers, along with 12 pilot and 10 guard tones, using a 128 point IFFT. A zero-padded cyclic prefix of length 32 as well as a zero guard interval of length 9 are then added, resulting in a 165 samples long OFDM symbol. Preamble and header are then added to the information carrying OFDM symbols to form the packet that is to be transmitted over the channel.

Time-frequency codes (TFC) are used to interleave OFDM symbols over 3 frequency bands. Frequency-domain and time-domain spreading are also used in conjunction with different coding rates to achieve the data rates of 55, 80, 110, 160, 200, 320 and 480 Mbps.

The MBOA channel model is based on the UWB channel model adopted by the IEEE 802.15.3a task group. It is clustered-ray indoor model with double-exponential decay, where the arrival times of clusters and rays follow a Poisson process and the multi-path amplitude/phase follow lognormal/uniform distributions. All the four reference channel environments defined by the task group are built into this model.

The MBOA receiver is an ideal receiver, where it assumes perfect knowledge of timing and channel and is intended to generate a baseline measure for receiver performance and to provide a framework to design and verify the performance of different pieces of a practical receiver. After converting the received OFDM time waveform into frequency domain, ideal channel compensation is done using the frequency response of the channel which is generated by the channel model block. The symbols are then demodulated, and the resulting bits are de-interleaved, decoded (using a Viterbi decoder with either hard or soft decision decoding) and descrambled and the transmitted packets are recovered. The transmitted and recovered bits are then compared to compute the Block Error Rate (BLER) and Bit Error Rate (BER) of the system under simulation.

DS-UWB Proposal

The SPW DS-UWB model is based on the PHY proposal for UWB standard to IEEE 802.15 Task Group 3a by the UWB Forum. The proposed system uses Direct Sequence CDMA with variable code lengths to provide data rates of 28–1320 Mbps over a spectrum of 1.75 GHz.

In DS-UWB transmitter, data bits are first scrambled using the same scrambler as the MBOA proposal. Forward Error Correction (FEC) is provided by Convolutional codes with coding rate of 1/2 and two different constraint lengths (K=6 or 4), where K=4 encoder is used for lower complexity at high rates. Additional coding rate of 3/4 is achieved by puncturing the encoder output, while some of the higher data rates use no FEC (coding rate=1). Encoded bits are then interleaved using a Convolutional interleaver. Two types of modulation are used, BPSK and 4-BOK (Binary Orthogonal Keying). Variable length codes (L = 1, 2, 3, 4, 6, 12, 24) are used to spread the modulated signal. Ternary codes are used for codes lengths of L=12 and 24, while for shorter code lengths one code with a single non-zero chip value is used. Pulse shaping is then performed using a root raised cosine low pass filter with 30% excess bandwidth.

The channel model in DS-UWB library is similar to the one in MBOA library.

The DS-UWB receiver is also an ideal receiver. Channel compensation is done using a matched-filter that is matched to the complex conjugate of the impulse response of the channel. The resulting signal is then de-spread and demodulated, the resulting bits are de-interleaved, decoded and descrambled and the transmitted data bits are recovered. The transmitted and recovered bits are then compared to compute the Block Error Rate (BLER) and Bit Error Rate (BER) of the system under simulation.

Bluetooth Wireless Technology

The Bluetooth system is based on version 1.0A of the specification (See Figure 2.). The transmitter contains the access code generation from the Bluetooth device address, packet generation, scrambling of the packet header and the payload, and a binary Gaussian frequency shift keying (GFSK) modulator. Currently HV1, HV2, and HV3 voice packets are supported by the system. HV1 includes a rate 1/3 3-bit repeat FEC, HV2 includes a rate 2/3 shortened Hamming code, and HV3 does not contain any forward error correction. With the ideal GFSK modulator, the system models the effects of the carrier frequency drift and the variation of the deviation factor.

The effect of frequency hopping in the baseband model is simulated through a multipath indoor channel model. Since the Bluetooth standard does not specify a channel model, a model based on the IMT2000 standard with six multipaths is used within the system. Both 79-hop and 23-hop sequences are available in the library.

Two types of demodulators are provided in the receiver, one using an envelope detector and the other using a frequency discriminator.

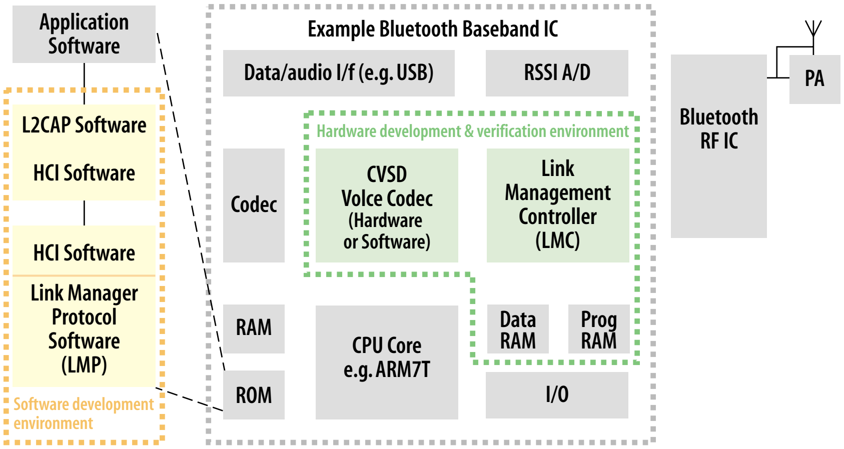

Figure 2. Example Bluetooth IC

The acquisition part of the receiver contains a tracking part that removes the dc offset from the demodulated signal. The signal is then decoded into bits and correlated with the access code available with the device. The presence of a packet for the device is signaled when the number of errors from the correlation is less than a specified value. When the signal is present the symbol timing is determined by finding the sampling point with the highest strength.

After sampling, the dc offset from these samples is subtracted before decoding the bits. The packet header and the payload are then descrambled and the packet header decoded. If the header error check passes the integrity check, the type of the packet is determined from the packet header. The packet type is used in the remaining processing of the payload. The system can be simulated for different Eb/No, multipath effects, and velocity of motion. Various parameters also select the frequency drifts, variation in the deviation factor, number of samples per symbol, error threshold for detection, and the packet type.

All these models are in compliance with the appropriate WLAN specifications. Our strategy is to rapidly update our product libraries as the standards change. Please contact Cadence for the current specification conformance status.

Key Library Blocks

Partial list of IEEE 802.11 DSSS blocks

- IEEE 802.11 DSSS Transmitter
  - IEEE 802.11 PLCP Frame
  - IEEE 802.11 Scrambler/De-scrambler
- IEEE 802.11 DSSS Receiver
  - IEEE 802.11 Acquisition
    - SYNC Code Matched Filter
  - IEEE 802.11 Timer
  - IEEE 802.11 Rake Receiver
    - IEEE 802.11 Rake Timing Tracking
      - Delay-Locked Tracking Loop Control
    - Simple Correlate and Dump
    - IEEE 802.11 Finger MUX
    - IEEE 802.11 Finger Select
    - IEEE 802.11 Header Decoder
    - Vector CRC

Partial list of IEEE 802.11a blocks

- IEEE 802.11a Transmitter
  - IEEE 802.11a PLCP Preamble
  - SIGNAL Field Encoder
  - IEEE 802.11a Data Scrambler
  - OFDM Transmitter
    - OFDM Encoder
      - IEEE 802.11a Puncture
      - Vector Interleave/De-interleave
    - Pilot Insert

        - Map FFT Vector
        - OFDM Modulator
        - Cyclic Extension
    - Window Function
- Impairments
    - Frequency Offset
    - Phase Noise
    - PA Model
        - PAPR Reduction
    - Wireless LAN Channel
        - WLAN Fade
    - IQ & DC Imbalance
- IEEE 802.11a Receiver
    - IEEE 802.11a Timing
    - Coarse Frequency Offset Compensation
    - Fine Frequency Offset Compensation
    - OFDM Demodulator
    - Pilot Remove & De-map
    - Channel Estimation
    - Carrier Phase & Timing Drift Correction
    - SIGNAL Field Decoder
    - OFDM Receiver
        - OFDM Decoder
            - OFDM Demodulator
                - Hard/Soft Demodulator
            - Rate & Length Decoder
            - IEEE 802.11a De-puncture
    - IEEE 802.11a Data De-scrambler

Partial list of IEEE 802.11b blocks

- IEEE 802.11b Transmitter
    - IEEE 802.11b PLCP Preamble
    - CCK Encoder
- IEEE 802.11b Receiver
    - IEEE 802.11b Ideal Channel Compensation
    - CCK Decoder
        - CCK Correlator

Partial list of IEEE 802.11g blocks

- IEEE 802.11g Transmitter
- IEEE 802.11g Receiver
- Plus all relevant IEEE 802.11a & 802.11b blocks

Partial list of IEEE 802.11n blocks

- IEEE 802.11n Channel Model

Partial list of MBOA UWB blocks

- MBOA Transmitter
    - MBOA PLCP Preamble
    - MBOA PLCP Header
    - Data Scrambler/De-scrambler
    - OFDM Transmitter
        - OFDM Encoder
        - Pilot Insert
        - Map FFT Vector
        - OFDM Modulator
        - Cyclic Extension
- IEEE 802.15.3a Channel Model
- MBOA Receiver
    - Channel Estimation & Compensation
    - OFDM Demodulator
    - Pilot Remove & De-map
    - OFDM Receiver
        - OFDM Decoder
            - OFDM Demodulator
                - Hard/Soft Demodulator

Partial list of DS-UWB blocks

- DS-UWB Transmitter
    - DS-UWB Frame Generation
    - Data Scrambler/De-Scrambler
    - DS-UWB Transmitter
        - DS-UWB Encoder
        - DS-UWB Symbol Map and Modulator
- IEEE 802.15.3a Channel Model
- DS-UWB Receiver
    - DS-UWB Channel Estimation & Compensation
    - DS-UWB Symbol De-map and Demodulator
    - DS-UWB Decoder
    - DS-UWB data recovery

Partial list of Bluetooth blocks

- Bluetooth Transmitter
    - Bluetooth Access Code
    - Bluetooth Packet Header
    - Bluetooth Voice Payload
    - Whitening PN Sequence
    - GFSK Modulator
- Hop 79 Sequence
    - Hop 23 Sequence
- Bluetooth Acquisition
    - Envelope Detector
    - Frequency Discriminator
    - Remove Sync DC Offset
- Bluetooth Decoder
    - Bluetooth Voice Error Check
    - Bluetooth Voice Decoder
        - Vector CRC
        - Repetition Decode

Customer Focus

CoWare provides a complete range of training, support, design methodology consulting, and integration services. Technical support requests are handled directly by experienced design engineers who are fully familiar with the application of CoWare tools and methodologies to real-world designs. Training courses are available at CoWare offices or at the customer site and can be tailored to meet the specific needs of the design team.

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