Estimation of Alpha-Stable Interference Model Parameters for WSNs using CupCarbon Simulator

Umber NOREEN
Supervisors: Ahène Bounceur and Laurent Clavier.

This work is part of the research project PERSEPEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Contents

PART I: PHY based on ZigBee/IEEE Standard 802.15.4 Communication System
  • What is IEEE Standard 802.15.4
  • Relation between ZigBee and IEEE Standard 802.15.4
  • PHY Frame Structure
  • Physical Layer Design

PART II: Estimation Of Two Parameters Of Alpha-stable Distribution
  • Alpha-Stable Distribution
  • OFDM Transceiver and Impulsive Noise

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Some applications demand low rate, low power consumption protocol stacks.

In 2000, IEEE New Standards Committee introduced a low-rate wireless personal area network (LR-WPAN) standard, called 802.15.4

It addresses the market needs for cost-effective and low power wireless networking.
802.15.4 standard uniquely fills a gap for low data rate applications.
IEEE standard 802.15.4 defines characteristics of PHY and MAC layers for LR-WPANs.

ZigBee builds upon the IEEE 802.15.4.

ZigBee defines network layer and application layer specifications.

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
IEEE 802.15.4 Defined Frequency Bands

- **2.4 GHz** (worldwide) PHY with channel 11-26

- **868 MHz** (Europe) PHY with channel 0

- **915 MHz (US)** PHY with channel 1-10

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
## Specifications Associated with Frequency Bands

<table>
<thead>
<tr>
<th>HY (MHz)</th>
<th>Frequency Band (MHz)</th>
<th>Chip Rate (k chip/s)</th>
<th>Modulation technique</th>
<th>Bit Rate (k bit/s)</th>
<th>Symbol rate (k symbol/s)</th>
<th>Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>868</td>
<td>868-868.6</td>
<td>300</td>
<td>BPSK</td>
<td>20</td>
<td>20</td>
<td>Binary</td>
</tr>
<tr>
<td>915</td>
<td>902-928</td>
<td>600</td>
<td>BPSK</td>
<td>40</td>
<td>40</td>
<td>Binary</td>
</tr>
<tr>
<td>2450</td>
<td>2400-2483.5</td>
<td>2000</td>
<td>O-QPSK</td>
<td>250</td>
<td>62.5</td>
<td>16-ary Orthogonal</td>
</tr>
</tbody>
</table>

Channel access via CSMA-CA

Range between 2km Los

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
The General Frame Format

The IEEE 802.15.4 MAC has four different frame types.

- **beacon frame**
- **data frame**
- **acknowledgment frame**
- **MAC command frame**

contain information sent by higher layers

originate in the MAC and are used for MAC peer-to-peer communication

<table>
<thead>
<tr>
<th>PHY Frame</th>
<th>MAC Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preamble Sequence (4 bytes)</td>
<td>Frame Control (2 bytes)</td>
</tr>
<tr>
<td>Start of Frame Delimiter (1 byte)</td>
<td>Sequence Number (1 byte)</td>
</tr>
<tr>
<td>Frame Length (1 byte)</td>
<td>Addressing Fields (4 or 10 bytes)</td>
</tr>
<tr>
<td></td>
<td>Frame Payload (variable)</td>
</tr>
<tr>
<td></td>
<td>Frame Check Sequence (2 bytes)</td>
</tr>
</tbody>
</table>
IEEE standard 802.15.4

We want to send the message \textbf{AB} \quad \text{Bits: } 0100000101000010 (40 41)

Physical Frame: \textbf{XX XX} 7E 01 00 00 40 41 00

Signal to send:
Functional Block Diagram of IEEE standard 802.15.4 Based Communication System

- Binary Data from (PPDU) → Bits to Symbol conversion → Spreading → O-QPSK Modulation → Wireless Channel → O-QPSK Demodulation → De-Spreading → Symbols to Bits conversion → PPDU receiver

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
IEEE standard 802.15.4 based Transceiver

1. Bit to Symbol
   &
2. Spreading

Physical Frame:
E4 A2 FB 45 6B B1 7E 01 00 00 40 41 E4

   E4

   1110 0100 ...

   01010010001011101101100111000011

   100101100000011101110110001100 ...

<table>
<thead>
<tr>
<th>Symbols (dec)</th>
<th>Symbols (bin)</th>
<th>PN-Sequence ($C_0, C_1,...C_{31}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0000</td>
<td>11011001111000110101001001011110</td>
</tr>
<tr>
<td>1</td>
<td>0001</td>
<td>11101101100111000011010100100010</td>
</tr>
<tr>
<td>2</td>
<td>0010</td>
<td>001011101011001110000110100010</td>
</tr>
<tr>
<td>3</td>
<td>0011</td>
<td>001000110110110011000011101101</td>
</tr>
<tr>
<td>4</td>
<td>0100</td>
<td>010100100010111011011100001101</td>
</tr>
<tr>
<td>5</td>
<td>0101</td>
<td>00110101001000101111011011011000</td>
</tr>
<tr>
<td>6</td>
<td>0110</td>
<td>11000011101010010011000110110101</td>
</tr>
<tr>
<td>7</td>
<td>0111</td>
<td>10011100011101010001000111101101</td>
</tr>
<tr>
<td>8</td>
<td>1000</td>
<td>100011010010100000111011011111</td>
</tr>
<tr>
<td>9</td>
<td>1001</td>
<td>1011100011001001100000011101111</td>
</tr>
<tr>
<td>10</td>
<td>1010</td>
<td>0111101110001100101010000001111</td>
</tr>
<tr>
<td>11</td>
<td>1011</td>
<td>01110111101100011000110101100000</td>
</tr>
<tr>
<td>12</td>
<td>1100</td>
<td>0000011101111011001000110010110</td>
</tr>
<tr>
<td>13</td>
<td>1101</td>
<td>011000000111011110110001100101</td>
</tr>
<tr>
<td>14</td>
<td>1110</td>
<td>100101110000011101110111000110</td>
</tr>
<tr>
<td>15</td>
<td>1111</td>
<td>11001001011000001101111011101000</td>
</tr>
</tbody>
</table>

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Spreading

Transmitted signal takes more bandwidth as the original signal.

DSSS phase shifts a sine wave pseudo randomly with a continuous string of pseudo noise (PN) code symbols called “Chips”.

- A Pseudorandom is a process that appears to be random but is not.

Each information bit is modulated by a sequence of much faster chips.

- Therefore: chip rate is >> information signal bit rate
- Chip rate: Chips per second

DSSS uses a signal structure in which the sequence of chips produced by the transmitter are already known at receiver.
Advantages of Spreading

Resistance to intended or unintended jamming.
Sharing of single channel among multiple users.
Reduce signal background noise
Resistance to interference
3 Basic Modulation Techniques

Amplitude Modulation

Frequency Modulation

Phase Shift Modulation
Offset quadrature phase-shift keying O-QPSK

- Encodes two bits per symbol, with four phases,
- Variant of phase-shift keying modulation using 4 different values of the phase to transmit.
- The sudden phase-shifts occur about twice as often as for QPSK (since the signals no longer change together).

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Offset quadrature phase-shift keying O-QPSK

Phase-shifts in QPSK result in large amplitude fluctuations, an undesirable quality in communication systems.

O-QPSK limits the phase-shift to no more than 90° at a time.

This yields much lower amplitude fluctuations than non-offset QPSK and is preferred in practice.

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
De-Spreading

Transmitted Value: 01010010001011101101100111000011
Received Value: 010100010010111011000011

Value with minimum hamming distance

Already known at receiver

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
IEEE Standard 802.15.4 Based Transceiver

Binary Data from (PPDU) → Bits to Symbol conversion → Spreading → O-QPSK Modulation → Wireless Channel

Interference

PPDU Receiver ← Symbols to Bits conversion ← De-Spreading ← O-QPSK Demodulation

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Characterization of Noise in Wireless Channel

- Thermal Noise
- Channel Response
- Intra-Network Interference
- Other types of Interferences
Wireless Environment

• **Received Signal**

\[ R_{\downarrow}x = h_{\downarrow}0 X_{\downarrow}0 + \sum_{i=1}^{\uparrow n} h_{\downarrow i} X_{\downarrow i} + N \]  

(1)

\[ \sum_{i=1}^{\uparrow n} h_{\downarrow i} X_{\downarrow i} = \sum_{i=1}^{\uparrow u} h_{\downarrow i} X_{\downarrow i} \quad \text{Impulsive noise} + \quad \sum_{i=1}^{\uparrow u} h_{\downarrow i} X_{\downarrow i} \quad \text{Gaussian noise} \]  

(2)

• Weak Interferers can be considered as Gaussian Noise source
• Strong Interferers can be considered as source of Impulsive Interference

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Alpha-Stable or Impulsive Noise

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Alpha-Stable or Impulsive Noise Model

Alpha-Stable noise or the impulse noise consists of irregular pulses or spikes that occur for short duration and also known as rare events in the channel.

Unlike Gaussian distribution, there is no closed form expression or pdf.

It can be described by using its characteristic function:

\[ \phi(\theta) = \begin{cases} \exp\left\{ -\sigma^\alpha |\theta|^\alpha \left( 1 - i\beta \text{sign}(\theta) \tan \pi \alpha/2 \right) + i\delta \theta \right\} & \text{if } \alpha \neq 1 \\ \exp\left\{ -\sigma |\theta| \left( 1 + i\beta^2/\pi \text{sign}(\theta) \ln |\theta| \right) + i\delta \theta \right\} & \text{if } \alpha = 1 \end{cases} \]

\text{sign}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}
Alpha-Stable or Impulsive Noise Model

\( \alpha \) is the index of stability: sets the degree of the impulsiveness. \((0<\alpha \leq 2)\).

- At \( \alpha = 2 \) this distribution becomes Gaussian distribution.

\( \beta \) is skewness parameter: Specifies the distribution curve if skewed towards right or left. \((-1<\beta \leq 1)\).

\( \sigma \) is scale/dispersion parameter: Measures the spread of the noise samples around the mean. \( \sigma > 0 \).

\( \delta \) is called location parameter: Corresponds to the median if \( 0<\alpha<1 \), and corresponds to the mean if \( \alpha \) have value \( 1<\alpha \leq 2 \). \( (\delta \in \mathbb{R}) \).
Let $Y$ denote the accumulated interference at the receiver node

$$Y = \sum_{i=1}^{n} Q_i$$

An arbitrary random quantity $Q_i = [Q_{i1}, Q_{i2}, \ldots, Q_{in}]$ is associated with each interferer $i$. The set of distances between the receiver node and several interferer nodes is denoted by $\{R_{\downarrow i}\}_{i=1}^{n}$. $b$ is the channel amplitude attenuation coefficient, and $\gamma$ is the corresponding power loss exponent.

$$\alpha = \frac{2}{b} \text{ and } \sigma = \frac{2\pi C_{\downarrow i}^2}{b} \Gamma^{-1} \left\{ E\{|Q_{\downarrow i}, n| \mid R_{\downarrow i} / b\} \right\}$$

\[ C_{\alpha} = \begin{cases} 
\frac{1 - \alpha}{\Gamma(2 - \alpha) \cos\left(\frac{\pi\alpha}{2}\right)}, & \alpha \neq 1 \\
\frac{2}{\pi}, & \alpha = 1
\end{cases} \]

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Parameter Estimation of Alpha-Stable Distribution

\[ \sigma = \lambda \pi C \downarrow 2 / b \uparrow 1 - 1 E\{Q_{i,n} | \uparrow 2 / b \} \]

For \( Q_{i,n} | \uparrow 2 / b \), let \( Q_{i,n} \) is Raleigh distributed then

\[ E[|Q_{i,n} | \uparrow 2 / b ] = 2 \Gamma 1 / b \ \epsilon \uparrow 2 / b \ \Gamma(1/b + 1) \]

\[ Y \sim S(\alpha \downarrow Y = 2 / b, \beta \downarrow Y = 0, \delta \downarrow Y = 0, \sigma \downarrow Y = \lambda \pi C \downarrow 2 / b \uparrow 1 2 \Gamma 1 / b \ \epsilon \uparrow 2 / b \ \Gamma(1/b + 1)) \]
BER performance of OFDM based Transceiver

- $\beta = 0$
- $\delta = 0$
- $b = 2$
- Radio range = 200m
- $\varepsilon = 10$ dB

BER < $10^{-2}$

Acceptable BER

50 to 300 nodes (10% active nodes)

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
PER performance of OFDM based Transceiver

Average PER of an OFDM system with Alpha-Stable Interference Model

- $\beta = 0$
- $\delta = 0$
- $b = 2$
- Radio range = 200m
- $\varepsilon = 10$ dB

50 to 300 nodes
(10% active nodes)

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
BER performance of 802.15.4 based Transceiver

- $\beta = 0$
- $\delta = 0$
- $b = 2$
- Radio range = 200m
- $\varepsilon = 10$ dB
- data rate = 64 Kbits

$BER < 10^{-3}$

Acceptable BER

50 to 300 nodes
(15% active nodes)

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Results with CupCarbon Simulator
Node-to-Node Transmission Model

\[ N = 3 \; ; \; S = 1 \text{ sec} \]
\[ i = 1 \]

Transmits Data
(802.15.4 + Alpha-Stable distribution)

Waiting for an ACK

ACK received in \( \leq S \text{ sec} \) ?

Yes (Data received)

Exit

\( i = i + 1 \)

\( i < N \) ?

Yes

No

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
Data Transmission & ACK Visualization from CupCarbon

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.
IEEE Standard 802.15.4

IEEE 802 LAN/MAN Standards Committee

- 802.1 Higher Layer LAN Protocols Working Group
- 802.11 Wireless Local Area Network Working Group
- 802.15 Wireless Personal Area Network Working Group
- 802.17 Resilient Packet Ring Working Group

- TG1 WPAN/Bluetooth Task Group
- TG2 Coexistence Task Group
- TG3 WPAN High Rate Task Group
- TG4 WPAN Low Rate Task Group

This work is part of the research project PERSEPTEUR supported by the French Agence Nationale de la Recherche (ANR) under the reference ANR-14-CE24-0017-01.