Enhanced Performance by Sub-1 GHz WSN Solutions based on IEEE 802.15.4-2006

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***Abstract*—PSSS (Parallel Sequence Spread Spectrum) [1] technology is the basis for the PHY of the new IEEE802.15.4-2006 standard with the enhancement for the data rate from 20 kbps to 250 kbps for the European area. Even robustness against multipath fading is enhanced and makes the sub 1 GHz PHY high attractive, even due to less inference probability, compared to 2.4GHz solutions and lower attenuation in the transmission path.**

I. INTRODUCTION

The sub 1 GHz PHY's of IEEE 802.15.4-2003 standard offer only 20 kbps for Europe/ETSI (European Telecommunications Standards Institute) and 40 kbps for the FCC region. Compared to the 250 kbps the data rate was unattractive, especially for WSN (Wireless Sensor Networks) with many subscribers. For the ETSI region has t be taken into account, that there is a duty cycle limitation of 1%. That causes average data rate of not more then 200 bps for the IEEE 802.15.4-2003 PHY. The peak data rate for the sub 1 GHz IEEE820.15.4-2006 PHYs (ETIS/FCC) is 250 kbps common to the 2.4 GHz PHY.

The coverage is for sub 1GHz bands less then for the 2.4 GHz band. Simulations with a ray tracing tool underline that fact. In figure 1 is shown the received power for a 2.4 GHz transmission for a LOS (Line of Sight) and a NLOS (No Line of Sight) area.

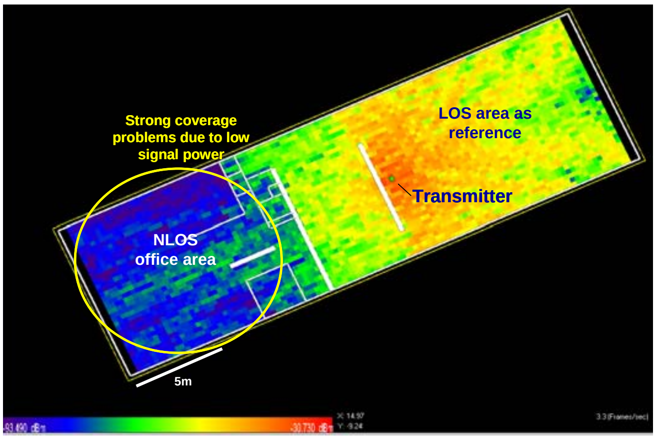

Figure 1. Coverage 2.4 GHz in LOS and NLOS area. Received power: blue -93,5 dBm, red -30 dBm

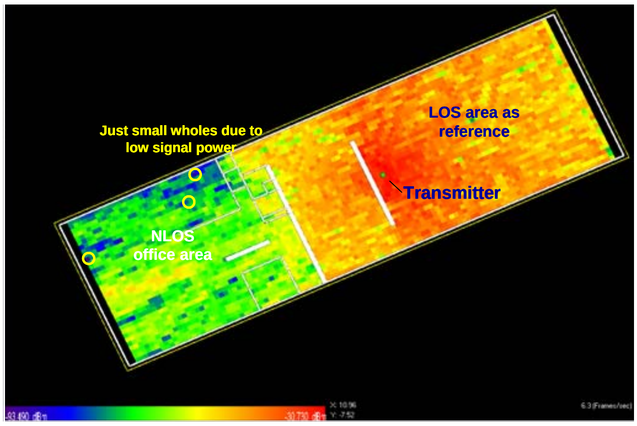

Figure 2. Figure 1. Coverage 868 MHz in LOS and NLOS area. Received power: blue -93,5 dBm, red -30 dBm

The 868 MHz example in figure 2 shows that the received power is significant higher. Even the expected interference is in the sub 1 GHz better then in the 2.4 GHz band. WLAN and Bluetooth are occupying the 2.4 GHz band.

The motivation for enhancing the data rate for the sub 1 GHz PHY in the IEEE 802.15.4-2006 standard was to combine the attractive coverage of the sub 1 GHz band and the low interference with the high data rate of the 2.4 GHz PHY. Especially for the ETSI area with the 1 % duty cycle limitation the increased data rate was necessary.

II. PSSS TECHNOLOGY

A. Basic

PSSS uses for the encoding m-sequences in parallel. Equitation (1) describes the base m-sequence ms_1.

$$ms_1 = \left(m_{11}, m_{21}, \ldots, m_{M1}\right) \tag{1}$$

The coding table is given by EN and contains cyclic shifted m-sequences of ms_1.

$$EN = \begin{bmatrix} m_{11} & \dots & m_{1N} \\ m_{21} & \dots & m_{2N} \\ m_{M1} & \dots & m_{MN} \end{bmatrix} \quad (2)$$

For the encoding the data D (3) is multiplied with EN (2).

$$D^T = \left(d_1, d_2, \dots, d_N\right) \quad (3)$$

$$S = EN \bullet D \quad (4)$$

Each data bit of D is spread with a cyclic shifted m-sequence. The spreaded bit are the added column wise. The decoding can be reached by cyclic cross correlating the PSSS-Symbol S with the base m-sequence ms_1. This operation is similar to using a matrix DE for decoding.

$$DE = EN^T \quad (5)$$

$$CCF = S \bullet DE \quad (6)$$

CCF presents the cyclic cross correlation between the PSSS symbol S and the decoder matrix DE. The reconstruction is done by threshold decision as described in (7).

$$d'_n(ccf_n) = \begin{Bmatrix} d'_n = 0;\ ccf_n \le \left(Max\{CCF\} + Min\{CCF\} \div 2\right) \\ d'_n = 1; ccf_n > \left(Max\{CCF\} + Min\{CCF\} \div 2\right) \end{Bmatrix} \quad (7)$$

$d'_n(ccf_n)$ is the reconstructed data word. Depending on implementation targets of PSSS different threshold algorithms are available.

For reducing the PAPR (Peak Average Power Ratio) and the DC component of the PSSS symbol S precoding could be used. The precoding of one symbol is executed independent of the precoding of any other symbol with the two steps described mathematically as follows:

$$S'(m) = S(m) + \frac{(Max + Min)}{2}$$

where S(m) is the current PSSS symbol and S'(m) is the aligned symmetric to zero PSSS symbol and Max and Min are the maximum and minimum chip amplitudes within the symbol respectively and

$$p''(m) = \frac{p'(m)}{A}$$

where A = (Max' – Min') and Max' and Min' are the maximum and minimum chip amplitudes within the aligned symmetric to zero PSSS symbol p'(m) respectively.

Precoding reduces the PAPR and therefore the demanded linearity of the power amplifier.

B. *PSSS for the IEEE 802.15.4-2006 sub 1 GHz PHYs*

Target for the new standard was [2] to reach 250 kbps even for the sub 1 GHz PHY. For the PHYs as base m-sequence was selected a 31 chip log sequence. From the resulting encoding matrix only a subset has been selected. Available are 31 cyclic shifted sequences. For FCC only five and for ETSI twenty sequences have been selected. That causes that for the given chip rate a data rate of 250 kbps is realized, both FCC and ETSI version of the PHY.

Selecting a subset of EN causes even that the distance between the correlation peaks of CCF (6) increases, which could be used for enhanced multipath fading robustness. The delayed multipath fading parts of the received signal are between the correlation peaks and don't cause ISI (Inter Symbol Interference), if the delay spread is shorter the distance between the CCF peaks.

For avoiding hurting the cyclic correlation for the decoder due to multipath fading the PSSS symbol S is cyclic extended similar to the cyclic extension of OFDM symbols. The extend PSSS symbol contains 32 chips.

III. Performance of PHY Implementations and Available Platform

For the ESTI an FCC PHYs of IEEE802.15.4-2006 are discrete FPGA based implementations available that have a sensitivity of less then -100dBm for 1% PER. The available link budget is about 120 dB or even more. Even in [3] a implementation as single chip is described.

IV. Future Steps

PSSS as technology is usable for WSN due to low power consumption and low cost implementations combine with unique data rate of 250 kbps for the ETSI region of the IEEE 802.15.4-2006 standard. The low complexity of PSSS implementations is opening the path to high data rate solutions, where OFDM implementations are limited in the reachable data rate. PSSS can be combined with well know technologies like deconvolution and MIMO for enhancing the multipath fading robustness. Even combination of PSSS and OFDM seam to be promising [4].

References

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[4] Paulo Isagani M. Urriza and Joel Joseph S. Marciano Jr., "A Flexible OFDM Spread Spectrum System Using Parallel Sequences", http://eee.upd.edu.ph/urriza/research.html.

The development of the discrete prototypes is granted by Europäische Union, Europäischer Fond für regionale Entwicklung. Investition in Ihre Zukunft. Allgemeine Informationen unter www.efre.brandenburg.de.