# Coexistence Optimization of Wireless PAN Automation Systems

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## Abstract

*Wireless technologies are being envisioned for industrial automation after their success in consumer electronics. Many wireless technologies are available today, where most important are IEEE 802.11 a/b/g for WLAN, and IEEE 802.15 for WPAN standards. Despite the advantages a single wireless technology might offer in an automation system, it will be often required to run multiple WLAN/WPAN networks in parallel in different or overlapping regions of the plant. Most of these technologies are working in the 2.4 GHz ISM band which is unlicensed and available all over the world. Because of this fact, it can be expected that all these technologies will interfere with each other. Thus the coexistence of multiple networks needs to be investigated and some parameters should be adjusted to optimize reliability and security of these technologies.*

*We suggest an easy-to-use coexistence measurement test site and investigated the coexistence properties of WPAN systems like Bluetooth IEEE 802.15.1, ZigBee IEEE 802.15.4, IEEE 802.15.4a based CSS, and narrowband FSK and suggest optimal parameter settings.*

## 1. Introduction

Wireless technologies are increasingly desired in numerous innovative applications of industrial automation. Meanwhile, a great variety of commercial wireless technologies are available which are offered as a large selection of OEM products. To avoid later disappointments technological limits should be considered early in the initial planning stage. Passive impairments, like multipath propagation and time varying channel responses due to movements, as well as active sources of disturbances have to be considered. The latter are caused by parasitic machine emissions and unintentional or even intentional other wireless systems [1, 2].

Many wireless technologies are available today. Most important are IEEE 802.11 a/b/g for WLAN, and IEEE 802.15 for WPAN standards. As most of the modern technologies work in 2.4 GHz ISM band it is expected that all these technologies become a potential source of disturbance for each other system if working in the same area.

The goal of this contribution is to study the achievable performance limits of state-of-the-art wireless PAN technologies from the viewpoint of prospective users in coexistence environments. The contribution studies the optimization of each technology and finds the suitable technologies which work best with respect to coexistence of a particular technology. These results can be considered as suggestions for the development of interference resistant wireless products.

## 2. Selected coexistence test sites

Bluetooth, ZigBee IEEE 802.15.4, WLAN, nanoNET CSS (chirp spectrum spreading), and narrowband FSK are selected for the investigations in this research project. A graphical comparison of some technology features is provided in Fig. 1.

The coexistence test setup which was used to investigate the coexistence of different systems is shown in Fig. 2. The distance between the DUT (device under test) transceivers and between DUT and interferer is identical. This distance $d$ should be selected as a typical distance with respect to the intended application. Following normative EMC measurements, we selected $d = 3$ m for all measurements. This distance is appropriate for PAN applications and enables measurements in most anechoic chambers.

The following parameter sets were used for the measurements:

1. *DUT = {Bluetooth, ZigBee, nanoNET, narrowband FSK}*
2. *Interferer = {Bluetooth, ZigBee, nanoNET, narrowband FSK, WLAN}*
3. *Coexistence Parameters = {Frequency, Transmission Power, Retransmission Mechanism, Error Correction Mechanism, Bitrate, Cycle Time, Packet Size, Bandwidth, No. of Interferers, SIR}*

The aim was to test as many combinations as possible. But it is important to mention that due to time and technological limitations it was not possible to

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investigate all possible combinations. That is why the authors do not claim that good and bad combinations found in this contribution are really the worst and the best of all possible combinations. But our results provide helpful results and recommendations for a successful deployment of wireless PAN systems for automation applications.

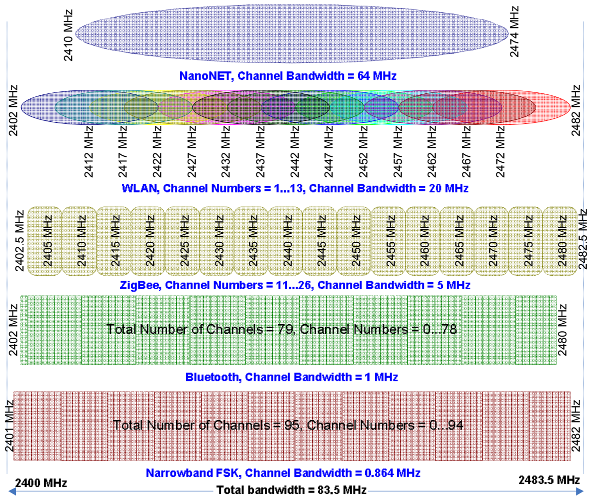


**Figure 1: Investigated technologies in the 2.4 GHz ISM band**

The DUT systems use a cyclic traffic application for process data transmission in a master-slave configuration. The master device generates a transmission packet, while the slave device returns it in a loop-back mode. The performance measurement parameters are packet loss rate (PLR), bit error rate (BER), packet delay (PD), and jitter.

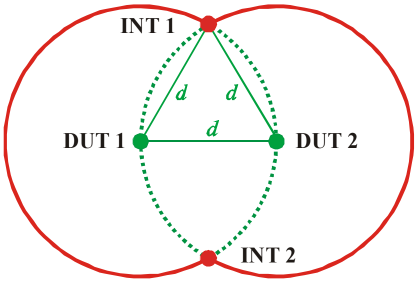


**Figure 2: Recommended equal-distance coexistence test site (*d* = 3m)**

All coexistence measurements were done in a lab environment and in an anechoic shielded chamber.

The interfering systems nanoNET, narrowband FSK, ZigBee, and Bluetooth generate cyclic interference traffic while WLAN generates asynchronous download traffic.

The nanoNET measurement setup used FEC with a (7, 4) HAMMING code and ARQ with maximum 5 retransmissions. 1Mbps bitrate was used while the transmission power was –16 dBm unless otherwise mentioned.

Atmel's ATR2406 transceiver without any error correction was used for narrowband FSK measurements. 500 kbps and 72 kbps bit rates were used. The transmission power of the ATR 2406 transceiver was 4 dBm while channel 13 (see Fig. 2) was used for transmission.

The WLAN system was only used as an interferer. An IEEE 802.11g based access point. It used channel number 2 (2.417 GHz center frequency) and 20 dBm transmission power. The channel number 8 (2.447 GHz center frequency) was only used where two WLAN systems were used for interference.

Two Freescale MC13213 boards [12] were used. Channel number 13 with center frequency 2.415 GHz and 0 dBm transmission power was used. It uses CRC as an error detection mechanism while no retransmission mechanism is used. Packets are discarded in case of detected errors.

An industrial sensor actuator interface (SAI) based on Bluetooth class 1 technology was used [2]. FEC and ARQ with maximal 5 packet repetitions were used for the measurements. The asynchronous transmission mode ACL with its packet length type DM1 and DM3 were used. 10 bytes payload was used for DM1 and 120 bytes for DM3.

Table I lists all technologies and interferers along with the corresponding SIR values.

**TABLE I: Technologies investigated vs. interference; SIR values are given in respective cells.**

| | Bluetooth | ZigBee | nanoNET | FSK |
|---|---|---|---|---|
| **Bluetooth** | - | -20dB | -36dB | -16dB |
| **WLAN** | 0dB | -20dB | -36dB | -16dB |
| **ZigBee** | 20dB | - | -16dB | 4dB |
| **nanoNET** | 36dB | 16dB | - | 20dB |
| **FSK** | 16dB | -4dB | -20dB | - |
| **no interferer** | AC | AC | AC | AC |

*Investigated technology* = *Technology used as interferer* =

## 3. Measured Results with and without Optimization

### A. Reference Measurements without interferers

The measurements taken in anechoic chamber and lab without interferers are used as reference values (see Fig.3). For the Bluetooth system no bit errors were detected while the PLR was 0 % in the anechoic shielded chamber (AC) and 8e–5 in the lab. The BER for ZigBee also remains zero in both environments while the PLR was almost 0.28 % in the AC and 0.32 % in the lab. For the nanoNET system the BER is in the order of 1e–4 in both environments and the PLR is 0 % in the AC and 0.3 % in the lab. For the narrowband FSK system the BER is 0.2 %, and

0.38 %, respectively and the PLR is 0.76 % and 0.9 %, in the AC and lab environments respectively.

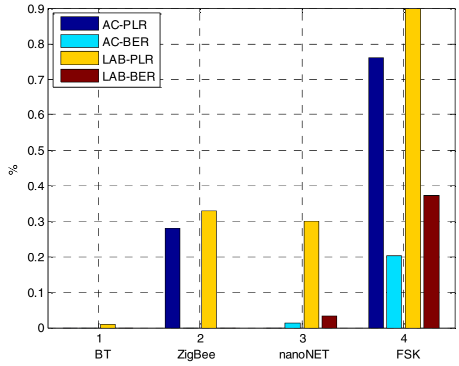


**Figure 3: Reference measurement: PLR and BER in an anechoic shielded chamber and LAB.**

### B. Coexistence without Optimization

The following parameters were selected only for the measurements in the lab environment presented in this subsection (see Fig. 4).

- Bluetooth packet type DM3 with 120 bytes payload size.
- NanoNET transmission power 6.90 dBm. ARQ and FEC turned off.
- Narrowband FSK bit rate 72 kbps.

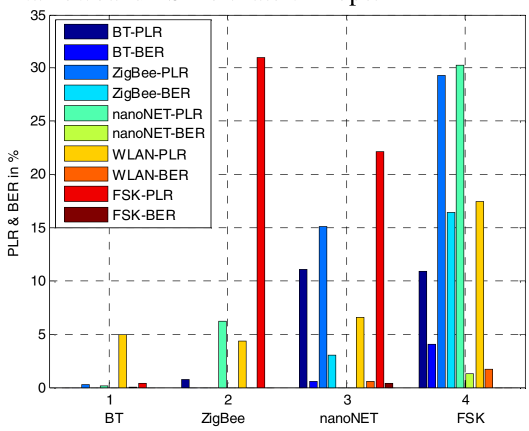


**Figure 4: PLR & BER without optimization for tested systems in the presence of selected interferers (legend shows interferers)**

*Bluetooth:* The maximum PLR is in the order of 5.0 % when two WLAN systems are used for interference. For all other interferers the PLR remains less than 0.4 %. The BER for the Bluetooth system is in the order 1e-5 when two WLAN interfering systems are used. Otherwise it remains zero.

*ZigBee:* The PLR is 0.74 % for Bluetooth interference, 6.24 % for nanoNET interference, 4.4 % for WLAN interference, and 30.9 % for narrowband FSK interference. The BER remains zero for all interferers.

*NanoNET:* The PLR is 11.1 % with Bluetooth interference, 15.1 % with ZigBee interference, 6.61 % with WLAN interference, and 22.2 % with narrowband FSK interference. The BER remains in the order of 1e-3 except for ZigBee interference. In the presence of ZigBee interference the BER is almost 3 %.

*Narrowband FSK:* The PLR is 10.9 % for Bluetooth, 29.3 % for ZigBee, 30.3 % for nanoNET, and 17.5 % for WLAN interference. The maximum value of BER is in the order of 16 % with ZigBee interference, for all other interferers it remains in the order of 1...4 %.

### C. Coexistence with Optimization

The optimization was done by changing either some parameters of the DUT itself (whenever possible) or of the interfering system. The following parameters were selected for the measurements presented in this subsection (see Fig. 5).

- Bluetooth packet type DM1 with 10 bytes payload size.
- NanoNET transmission power –16 dBm. ARQ and FEC turned on.
- Narrowband FSK bit rate 500kbps.

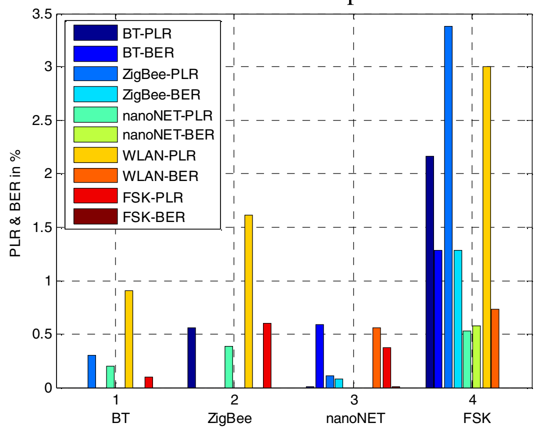


**Figure 5: Optimized PLR & BER for tested systems in the presence of selected interferers (legend shows interferers)**

*Bluetooth:* The PLR is between 0.1 % … 0.3 % for all interferers except WLAN. The maximum PLR value of 0.91 % is observed when WLAN is used as an interferer. The BER remains zero with all interferers.

*ZigBee:* The BER remains zero in all coexisting environments while the maximum value of PLR was 1.6 % for WLAN interference. The PLR remains between 0.3 % … 0.6 % for all other interferers.

*NanoNET:* The PLR remains less than 0.4 % for all coexisting systems. The BER is in the order 1e–4 … 1e–5 for narrowband FSK and ZigBee systems and almost 0.6 % for Bluetooth and WLAN coexisting systems.

*Narrowband FSK:* The PLR is 0.5 % for nanoNET interference and between 2 % … 3.5 % for all other coexistence environments. The BER remains in the order 0.6 % ... 1.3 % with different interfering systems.

Furthermore on the basis of results discussed in subsections A, B, and C the following conclusions can be drawn:

- A low bit rate (72 kbps) for the narrowband FSK system increases the collision probability of its symbols with those of the interfering systems, hence impairing the transmission performance of the FSK system in a coexistence environment.

- The nanoNET system is a very convenient interferer because of its very low power transmission. Except from the FSK system all other systems exhibit very good results in the presence of a nanoNET interferer. This holds even when the nanoNET system transmits with its maximal power level of 6.90 dBm. The high PLR of FSK is in fact because of low bit rate of FSK itself as discussed before.
- WLAN is the worst interferer for the FHSS based Bluetooth system as it offers 0 dB SIR and covers 20 MHz of the frequency band. I.e. 20 Bluetooth channels will be skipped by the adaptive frequency hopping algorithm. Though nanoNET effects even 64 Bluetooth channels, there is less interference due to the high SIR value of 36 dB.
- The Bluetooth system is an excellent DUT choice in coexistence environments.

### D. Jitter of packet delay

The jitter of the investigated systems in the anechoic shielded chamber (AC), lab environment without any interferers (LAB), overall minimum (Coex-MIN) and overall maximum (Coex-MAX) in all coexisting environments is shown is Fig. 6. The values greatly depend on the selection of the DUT parameters itself. The number of interferers, the retransmission mechanism, FEC, and the bitrate are found most influential parameters for delay and jitter measurements.

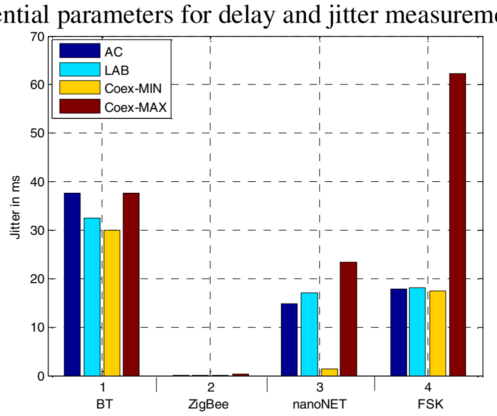


**Figure 6: Jitter in anechoic shielded chamber, lab, and coexistence environments.**

*Bluetooth:* The jitter values for the Bluetooth system remain in the order of 30 … 37.5 ms in AC, LAB and coexisting environments. The maximum jitter 37.5 ms was observed when two WLAN systems were used for interference.

*ZigBee:* The ZigBee system exhibits the lowest jitter among all investigated DUTs with values in the order 0.036 … 0.384 ms in all environments.

*NanoNET:* The lowest jitter value measured in an coexisting environments was 1.34 ms which was measured when both FEC and ARQ are disabled. The jitter remains in the order 15 … 23 ms in all environments when ARQ and FEC are used.

*FSK:* The jitter for narrowband FSK remains almost 18 ms in all environments except for nanoNET interference. The maximum jitter 62.26 ms was observed for the FSK system with 500 kbps when it was working in the coexistence of the nanoNET system.

## 4. Summary

Bluetooth, narrowband FSK, ZigBee IEEE 801.15.4, and nanoNET systems were investigated for implementation in automation systems and as interferer as well. The WLAN system was only used as an interferer. Transmission power, retransmission mechanisms, error correction mechanisms, bitrate, cycle time, number of interferers, bandwidth, and packet size are the investigated radio system features.

On the basis of a proposed equal-distance coexistence measurement the study suggests a thorough frequency allocation in a coexistence environment. The study suggests that low transmission power should be used in coexisting environments especially in the case when systems are using high bandwidth where spectral separation is not possible. The retransmission mechanisms should be used with minimum number of retransmissions as retransmissions increase the jitter. Furthermore, a minimal number of retransmissions limits the time coverage of the channel and therefore the interference probability. Small packet sizes and high bitrates are more suitable in coexisting environments to further reduce the collision probability. Forward error correction mechanisms should be used carefully as those mechanisms impair the transmission performance in bad channel situations. If possible, the cycle times of adjacent systems can be used to time synchronize the coexisting systems to get better results.

## 5. References


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