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Wireless performance tests for testing the robustness of a wireless communication link on multipath connected digital and coexistence

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Company
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Date and location
Wireless congress systems & applications
12-13 November 2014, Munich, Germany

Abstract
In this paper, we consider how wireless performance of a radio implementation can be tested in a representative way. It will be explained that for adequate and representative wireless performance testing multipath and coexistence aspects should be taken into account. The paper introduces the term Power Delay Spread (PDS) as the parameter that describes the multipath reflection behavior of environments and how we can use this parameter in order to achieve a reproducible and defined multipath wireless performance test. Moreover, the wireless performance depends on how well the system can coexist with other wireless communication systems. The relevant parameters for requirement setting of wireless systems will be explained. The paper describes the pros and cons of some implementations of test configurations, i.e., how well the mentioned aspects of multipath and coexistence are covered in certain test configurations. We will present a fully-multipath test configuration with some example test results, where both multipath and coexistence can be taken into account in order to test the radio implementation adequately.

1. Introduction

The trend of increasing number of wireless communication systems is already going on for many years [1][2]. This trend had gotten an even bigger boost after the world-wide acceptance and use of smart phones. With all kinds of dedicated apps, products or locations can now be controlled or monitored at distance.

A nice example of this application is the introduction of all kinds of mesh networks for remote control purposes, e.g., the remote control of lamps. These lamps communicate in a mesh network using a 802.15 type of radio (Zigbee light link). A bridge links this mesh network to the internet, which gives the opportunity to control the network and the connected lamps by smart phones at distance. All kinds of similar developments and products might be observed in the area of wireless sensors for either domestic or industrial applications. Corresponding to this trend is that radios and antennas need to be integrated in products or systems in order to enable wireless functionality. Typically, this integration is a challenge because the antennas need to be integrated in products with small form factors and which include many other metal or dielectric objects which can deteriorate the aimed antenna performance. In general, a requirement is put on the antenna efficiency or the antenna pattern in order to guarantee a required propagation range that enables the aimed application. This means that the antenna properties should be part of the wireless performance test, as will be discussed later on in more detail.

The wireless communication systems are operating in all kinds of different environments dependent on the application, e.g., in-home, urban, parking garages, offices, etc. These environments will cause reflections so that simple free-space calculations and corresponding free-space tests are not adequate, although still useful for getting insight. We call these environments multipath environments. Moreover, the wireless communication systems should be able to operate in coexistence with other wireless systems. For that reason, testing wireless systems on their performance and robustness should include these multipath and coexistence aspects. For that purpose, we start in the next section with

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the technical background of multipath and coexistence and how these aspects fit in the overall picture of requirement setting and verification of wireless systems. We use this technical background for surveying and assessing the possibilities of test configurations for wireless testing in section 3. In section 4, we subsequently will present a fully-radiated wireless performance test configuration that is able to test performance under multipath and coexistence conditions. We end this paper by wrapping up the main topics and conclusions.

2. Technical background

2.1 Requirement setting of wireless systems

In this paper, our topic is about wireless performance testing. However, before we can start a relevant discussion and evaluation of wireless performance tests we should remind that testing is just one phase in a bigger development cycle. The configuration for testing the wireless performance needs to correspond with the defined system requirements. In other words, wireless performance testing should be seen as part of a system-engineering approach where proper requirement setting is essential. In a system-engineering approach higher level requirements are translated to lower level requirements. This process is called requirement breakdown. In Table 1, an overview is given of how such a requirement breakdown might be performed for a generic wireless communication system.

An important conclusion out of this overview is that wireless performance and its corresponding verification tests should cover the following four aspects:

1. Behavior of the implemented antenna (efficiency and pattern);
2. Representative layout of board/application including other electronics (to take self-disturbance into account);
3. Multipath environment to emulate reflections as present in actual application environments;
4. Coexistence performance with other wireless systems.

Table 1:

Requirement breakdown levels	Examples
Customer needs and intended used	Wireless remote control applicable in and around a typical European house
Propagation range	30 m and accounting for reflections and losses in walls and floors
Platform / technology choice: This selection should also include considerations of how the system operates together with other wireless systems.	Light link / RF4CE (Zigbee) 802.15 at 868 MHz or 2.4 GHz
Chip set selection: This selection should consider the maximum output power and the sensitivity, which fundamentally defines the wireless performance as a basis.	Output power>3 dBm Sensitivity>-90 dBm
Antenna implementation / efficiency / antenna pattern: • Efficiency relates to Total Radiated Power (TRP) • Antenna pattern relates to Equivalent Isotropically Radiated Power (EIRP) • Antenna diversity: requires a radio suitable for it as well as careful positioning of the antennas	TRP>0 dBm EIRP pattern: no dips lower than -20 dBm
Antenna matching: To achieve high enough antenna efficiency the matching (return loss) should be low enough.	Return loss < -6 dB
Component and board layout: Other electronics should not generate intolerable interference.	Keep high speed interfaces (e.g., DDR memory, video, clocks) and switch mode power supplies away from radio and antenna(s). Proper layout is essential to prevent self-disturbance.

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When we start to assess possible test configurations for wireless verification and evaluate their pros and cons, we will consider the four aspects again and evaluate how well they are covered in various test configurations.

2.2 Multipath conditions caused by reflective environments

Wireless communication systems typically operate in environments where the radiated waves between transmitter and receiver are reflected by objects in those environments, e.g., by walls, floors, buildings, furniture, etc. These reflections cause that the transmitted signal is received at the receiving antenna not as a single wave, but as multiple waves due to the multiple reflections. For that reason, these reflective environments are called multipath environments. In such multipath environments the simple free-space calculations are not valid anymore.
The multiple waves as caused by the reflections will arrive at the receiver at different times (due to multiple paths) and from different angles. The different times of reception can potentially cause so-called inter-symbol interference, i.e., a signal of one symbol is received at a moment that actually the time-window of the new symbol is already active. The different angles of arrival indicate that the antenna pattern will have an influence on received signal strength. Dedicated studies considering the antenna's gain property in multipath environments (Mean Effective Gain (MEG)) might be found in [3]. The reflections cause standing waves meaning that relative small changes in position can change the received signal. The various objects that cause reflections will also cause additional fading loss in addition to the normal free-space pathloss. In summary, a multipath environment causes:

- Standing waves (different levels at different positions),
- Multiple received signals in time,
- Multiple received signals from different directions,
- Fading loss caused by the reflective objects.

These multipath aspects are important when we want to test a wireless communication system on its robustness when it should be able to operate in a specific multipath environment. In subsection 2.1, we have underscored the importance of a system-engineering approach. This means that already in the concept phase the intended use and correspondingly the intended environment should be determined. This is important because different environments behave differently for electromagnetic waves and this should be covered in proper requirement setting and corresponding verification. The above-listed aspects of multipath are actually not appearing as separate (independent) aspects, but rather as complex combined phenomena. All these properties together, which appear as a statistical phenomenon, are expressed in a parameter that is called the RMS delay spread, which is derived from the Power Delay Spread (PDS) profile [4]. The delay spread can be interpreted as the time difference between the arrival times of the most significant wave (often line-of-sight component) and the latest wave. When we want to test the performance of a wireless system properly, we should measure it in a test facility that emulates the actual (intended) environment by calibrating it by a similar PDS. Examples of measured PDS profiles of various real environments (office rooms and house rooms) are shown in Figures 1 and 2.

The mean delay spread is defined in Eq. [1] and the RMS delay spread is defined in Eq. [2].

Eq. 1:

$$\bar{\tau} = \frac{\int_0^\infty \tau \cdot A_c(\tau)\, d\tau}{\int_0^\infty A_c(\tau)\, d\tau}$$

Eq. 2:

$$\tau_{RMS} = \sqrt{\frac{\int_0^\infty (\tau-\bar{\tau})^2 \cdot A_c(\tau)\, d\tau}{\int_0^\infty A_c(\tau)\, d\tau}}$$

In these equations, $A_c(\tau)$ is the PDS profile of the specific channel in a specific environment.

Figure 1: Example PDS results of an office environment

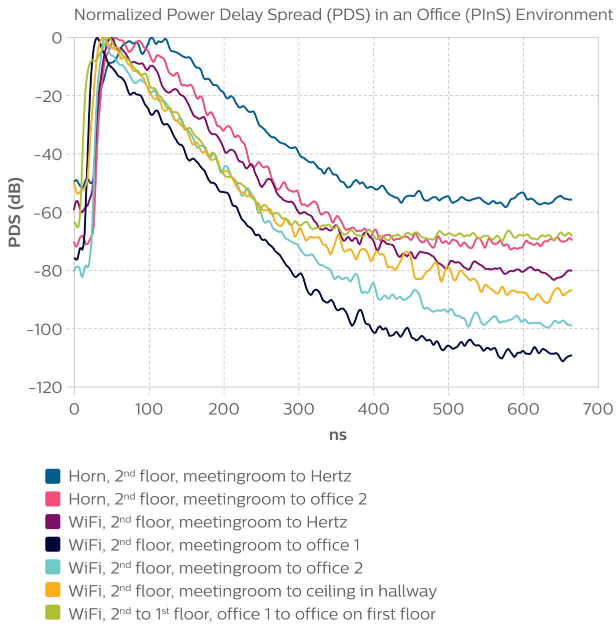
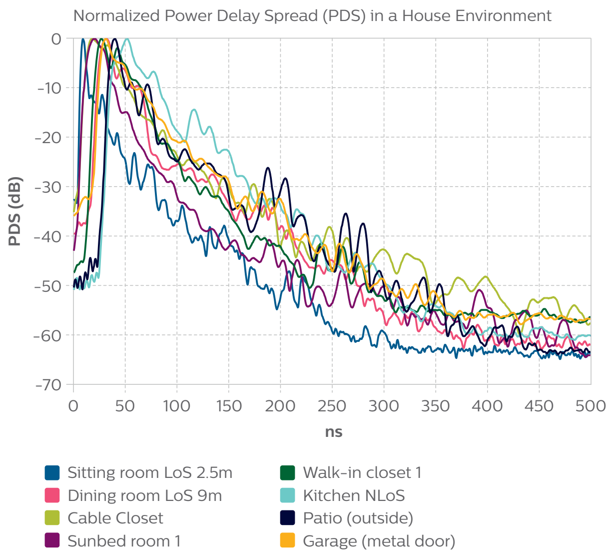


Figure 2: Example PDS results of a home environment



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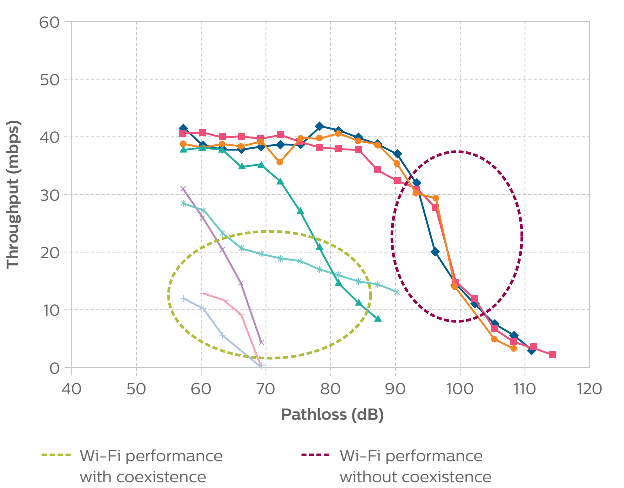
2.3 Robustness against coexistence

Besides the effects of multipath, a wireless communication system should also be able to operate together with other wireless communication systems, either same types (e.g., Wi-Fi versus Wi-Fi) or different types (e.g., Wi-Fi versus Zigbee [5] or Wi-Fi versus Ultra Wide Band (UWB) [6][7]). Coexistence between same types of communication systems is very often covered by the protocol as is the case for Wi-Fi. Also the new version 1.8.1 of the ETSI EN 300 328 standard includes many additional requirements related to the robustness against coexistence. It is actually the management of the use of a common communication band. Hence, they call it medium utilization aspects as well. The interference of a coexisting wireless system can be in-band or out-band. Out-band interference is less worse than in-band interference, but can still have a high impact; the interference can cause higher noise levels (deterioration of the sensitivity) or disturbances caused by non-linear effects. Anyhow, it is appropriate to verify the wireless communication system under real stress levels, this means that the performance should also be verified when another wireless communication system is active in proximity. A test configuration for wireless performance should have the ability to take coexistence into account. There are also opportunities to emulate other wireless communication signals in a simple way [1]. An example of how Wi-Fi performance can deteriorate significantly by proprietary wireless audio links is presented in Figure 3. Here the Wi-Fi performance results without coexistence are highlighted with a solid green ellipse. The other Wi-Fi performance results are with coexistence disturbance from various wireless audio links and are highlighted with a dashed red ellipse.

Figure 3: Example of coexistence impact (Wi-Fi disturbed by proprietary wireless audio links)



3. Overview possible test xonfigurations and their pros and cons

Various test configurations are possible to test wireless performance; an overview is given in Table 2. The first two are conducted and free-space test configurations and are quite straightforward. An example of a semi-multipath test configuration might be found in [8]. The fully-multipath configuration will be discussed also in section 4 of this paper

We remind from our discussion in subsection 2.2 that multipath includes:

1. Timing behavior (important for inter-symbol interference),
2. Fading behavior (pathloss, wall and floor losses, losses caused by other objects, etc.),
3. Spatial-geometric behavior (angle of incidence, polarization, etc.).

For that reason, proper multipath emulation should include these three aspects. When testing in a semi-multipath test configuration, the timing and fading behaviors are covered only, because in the anechoic chamber itself no reflections exist. This actually means that the antenna pattern behavior of the wireless system under test and its expected impact on multipath robustness is not taken into account. The fully-multipath test configuration combines all three multipath aspects, because we really have reflections causing that various waves are arriving at different times, with different attenuations (fading), and from different directions. Although both semi- and fully-multipath configurations can be calibrated with the right PDS of the radio channel of the emulated environment, the combination of timing, fading, and spatial behavior of real reflections are only covered in the fully-multipath configuration. The PDS includes the properties of the radio channel in an environment. In a semi-multipath configuration this is implemented separately by a fading box [8][9], where on the other hand it is inherently implemented in a fully-multipath configuration. In a semi-multipath configuration, the fading box includes the PDS information of the channel, where in a fully-multipath configuration the PDS is calibrated as (inherent) part of the entire test chamber environment (Faraday cage+absorbing blocks). This also indicates a minor disadvantage of the fully-multipath test configuration, namely the test chamber dimensions are critical in order to be able to emulate certain actual environments. For example, we need a test chamber of around 30-60 m^3 in order to emulate a small to medium sized house.

Table 2:

No.	Test configuration	Environment
1	Conducted	Cable connection only
2	Free-space	Anechoic chamber
3	Semi-multipath	Anechoic chamber with time/phase emulated multipath
4	Fully-multipath	Faraday cage (reflective chamber) with added absorbing blocks to emulate the Power Delay Spread (PDS)

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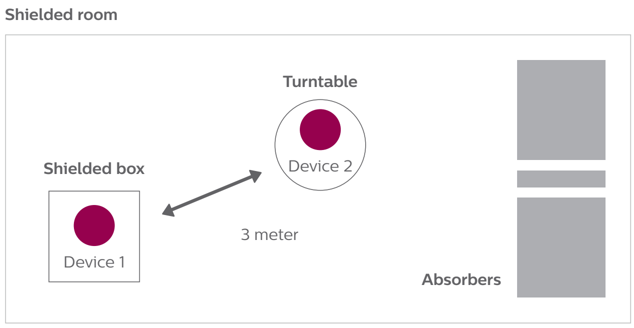
4. Fully-radiated multipath coexistence test configuration

An overview and a picture of an example of a fully-multipath test configuration have been shown in Figure 4. The basis is a Faraday cage equipped with absorbing blocks on one wall. The reference unit (e.g., reference Wi-Fi router) is placed inside a shielded box including a programmable attenuator. This attenuator emulates the increasing propagation range. The wireless device under test is placed on a turntable. For every attenuator step, the turntable with wireless device under test makes a full rotation clockwise and counterclockwise back (around 2 minutes). The average performance indicator (throughput, Packet Error Rate (PER), etc.) can be determined after this 2 minutes rotation. This rotation is needed to obtain statistical samples of the spatially distributed waves due to reflections. The reproducibility of this process is within ±1 dB. Subsequently, this process is repeated for other attenuation steps. The attenuation corresponds to propagation range (additional floor and wall losses should be taken into account in various scenarios) and the result will be a performance plot versus attenuation/propagation range. This measurement method can also be performed including another active wireless communication system in order to test the performance for coexistence robustness. The PDS profile of the fully-multipath test configuration in the Faraday cage is shown in Figure 5.

Figure 4: Overview of the fully-multipath configuration, schematic top-view (top) and picture (below)



The RMS delay spread of the fully-multipath test configuration with this absorbing block combination is around 20-25 ns, similar to a small to medium sized house (see Figure 2). We can vary the PDS profile of the test configuration by removing or adding absorbing blocks. An overview of typical RMS delay spread values for typical environments is shown in Figure 6.

Figure 5: PDS profile of the fully-multipath configuration (Faraday cage)

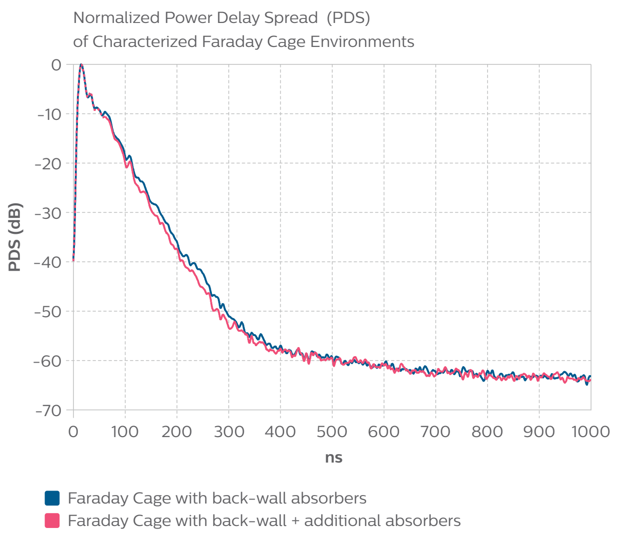
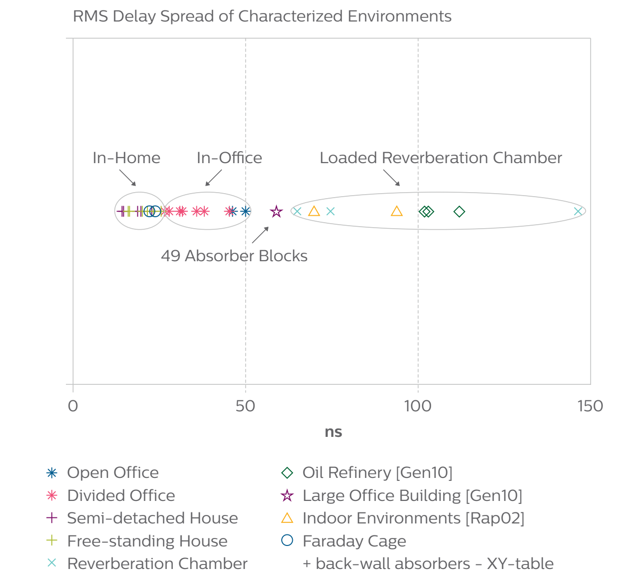


Figure 6: Overview of typical RMS delay spread numbers for various typical environments



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5. Summary

In this paper, we have made an overview about how wireless performance can be tested in a representative and reproducible way. It is explained that wireless performance should be considered from a system-engineering approach, where proper requirement setting and corresponding verification are mutually aligned. For that reason, wireless performance tests should also include multipath and coexistence aspects. In other words, wireless performance testing should be performed under realistic stress conditions in order to test robustness of the performance.

A representative test configuration should therefore cover the three important multipath behaviors (the timing, fading, and spatial-geometric behavior) in order to test wireless performance representatively. Also part of the system-engineering approach is the determination of the intended use of the system and its intended user-environment. The Power Delay Spread (PDS) profile of the test configuration should be calibrated to be similar to the intended user-environment. The PDS profile includes the relevant timing and fading properties of the communication medium.

It is presented that a fully-multipath test configuration only can cover the relevant multipath behaviors. This method is compared to a semi-multipath configuration and limitations of the latter are discussed. The fully-multipath test configuration can also be combined with coexistence testing. By applying this method, representative wireless performance tests with realistic stress conditions can be performed in a reproducible way. Practical example results are presented including an overview of typical PDS values for typical environments.

Acknowledgement

The author likes to express his gratitude for the support given by his Philips colleagues: Marcel van Doorn, Jaco van der Merwe, and Eddy Dejong, for reviewing and improving this paper and for delivering some relevant pictures used in this paper.

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