Over-The-Air Test Strategy and Testbed for Cognitive Radio Nodes

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Abstract

In this paper, an over-the-air test strategy for evaluating cognitive radio nodes is presented. This technique allows to emulate the activities of primary and secondary users with respect to received power spectral densities, and the spatial structures of their radio channels. This enables an experimental evaluation of cognitive devices with directional and spectral sensitivity. This type of testing is more realistic than conducted tests, as it includes all antenna effects involved in the perception of the radio environment. A multi-level test procedure is proposed, which implements different levels of complexity in terms of the operation of the device-under-test, the synthetic radio environment, and the required complexity of the test setup. A proof of principle based on an experiment is presented.

1 Introduction

Cognitive radio (CR) is an emerging technology for a more efficient use of spectrum resources as well as for self-organized mobile networks [1]. The main characteristic of CR is dynamic spectrum access to radio resources which are unused by primary users (PUs). However, radio devices with cognitive capabilities will encounter new challenges in the certification process [2]. Test procedures are required for performance evaluation and for confirmation that cognitive devices will not interfere with PUs. Moreover, it is highly probable that CR terminals will be handheld devices and will use multi-antenna techniques for increased throughput or directional operation. That is, the nodes are mobile and the height-over-ground of their antennas is not large compared to the height of surrounding objects. As a consequence, the environment has a strong influence on the wireless transmission to and from the nodes. The spreading of angles of arrival, or angles of departure, that is caused by reflections from objects in the environment, is an important aspect and cannot be ignored. Therefore, the antenna system is a major factor in the performance of the CR device. Generally, it is difficult to evaluate antenna performance separately, meaning the device has to be tested as a unit, apart from the fact that for integrated devices it is impossible to physically separate antennas from the device. We propose to test CR prototypes over-the-air (OTA). Although not exhaustive, OTA testing provides valuable information on the interaction of the CR device with the propagation environment, information that is not available otherwise. In particular, for devices with multiple antenna elements, this test enables a realistic verification of functions that depend on the spatial structure of the radio channel.

2 Cognitive radio node properties

According to Joseph Mitola's cognition cycle, the basic capabilities of a CR are *observe*, *orient*, *plan*, *decide*, *act*, and *learn* [3]. Without going into details of their realization, generally a CR node is built on a software defined radio (SDR). This allows for the reconfiguration of radio frequency (RF) parameters during operation, if the frontend is equipped with reconfigurable RF hardware. To be aware of the surrounding radio environment, a CR node performs spectrum sensing which reflects the capability *observe*. This provides information about the spectrum usage characteristic across multiple dimensions such as time, geographical space (location), frequency, code, angular dimension (direction), or types of signals [4]. The observed data are fed into an intelligent processing that reflects the capabilities *orient* and *plan*. Based on the results of this processing, the CR node *decides* on spectrum opportunities and on its transmission mode. Accordingly, the node dynamically adjusts its internal parameters to exploit these opportunities, however, under the strict constraint to avoid interference to primary users. This corresponds to the capability *act*.

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Moreover, *learning* from previous events is a vital capability. Obviously, a CR node exhibits a high flexibility in its functionality: operation over a wide frequency band, operation with different transmission technologies, and direction-selective operation when fitted with multiple antennas. This results in a number of challenges with respect to hardware and software implementations, as well as measurement methods for evaluation.

3 Test strategy

The essential characteristic of the OTA test strategy consists in the emulation of a defined authentic radio environment surrounding the device-under-test (DUT). Thereby, the following aspects are taken into account: number and geographical distribution (positions) of PUs and secondary users (SUs), temporal dynamic behaviour of their output powers and frequencies, and their radio channel characteristics including the angular power spectrum at the location of the DUT. To mimic these parameters realistically, suitable models have to be used which reflect the behaviour of the observed primary or secondary system. Generally, the test is performed in an anechoic chamber, to avoid interference from and to the outside world. N emulation-antennas are individually driven by synchronized dedicated signal generators, to generate an electromagnetic wave field with predefined structure at the DUT. Each of these emulation-antennas can be driven independently by its own RF signal generator, which is able to play back multiple user signals simultaneously and to introduce individual tapped delay line processing. The radiation from an emulation-antenna mimics reflections of an user signal from an object that is seen in or close to the direction of the emulation-antenna. To perform a closed-loop test, also the uplink has to be established. One option is a cable connection. However, a cable would distort the antenna pattern of the device. Therefore, an additional pick-up antenna in the anechoic chamber is preferred. If a cable connection is indispensable, optical fibre should be used. Furthermore, to monitor the internal states of the node in real-time and use it for further processing in a hardware-in-the-loop test, an optional status channel proves useful. Otherwise, the raw sensed data or the processed data have to be stored internally in the device and retrieved off-line. Figure 1 shows a block diagram of the test setup. Great care has to be taken for the preservation of the synchronization between the emulated signals and the sensed data. Despite of the potential for emulating realistic propagation scenarios, with increasing complexity of the emulated synthetic radio environment, the complexity of the signal generators will increase rapidly due to the demand on tapped delay line resources.

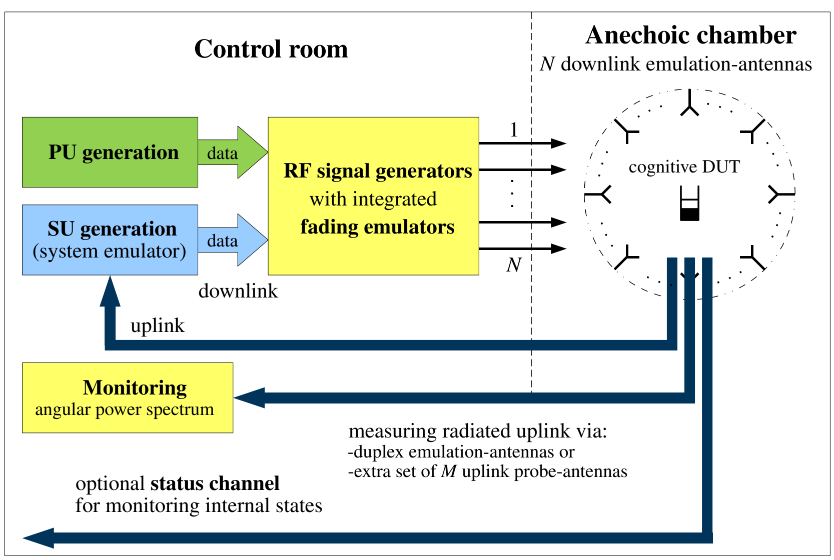

Figure 1: Block diagram of the OTA test setup.

First and foremost it is a test for prototype CR devices, focusing on the interaction between all communication layer-specific functions and components. That is, although software-related functions, implementing the capabilities *orient*, *plan*, *decide* and *learn*, will be validated independently, they are not excluded in the test. However, the emphasis of the OTA test is on evaluating the influence of the antenna system and the related signal processing on the overall performance. Functions implementing the capabilities *observe* and *act* are in the foreground. Nevertheless, status data can be read out through the status channel which are related to higher layers of the OSI reference model. For our test strategy, we defined four test levels. These differ in the complexity of the synthetic radio environment, as well as the testability of certain functions of the device. Level 1 and 2 verify the receive mode only, thus the focus is on *observe*, in particular on directional spectrum sensing. Here, the ability of spatial separation between PUs and SUs shall be tested. Level 3 and 4 include also the uplink and are thus associated with the capability *act*. In this, the exploitation of spectrum opportunities shall be tested with features like dynamic frequency and power control, adaptive modulation, adaptive coding, and beam-steering. The difference between test level 1 and 2, or test level 3 and 4, is in the assumed radio channel characteristic. Level 1 and 3 emulates a dominant LOS environment, only, while level 2 and 4 allows also rich multipath, table 1 gives an overview. Example scenarios of the test levels 1 and 4 are given in figure 2 and figure 3, respectively. In the test levels 3 and 4 the transmission in the direction of another SU shall be tested. To verify directional transmissions, the radiated angular power spectrum of the cognitive DUT has to be measured. Two techniques are possible. One is using the emulation-antennas in half-duplex, transmitting the signals of PUs and SUs, receiving the signals from the cognitive DUT. The second is using An extra set of M uplink probe-antennas. The received signals can be monitored and processed off-line in the same way near-field antenna measurements deliver radiation patterns.

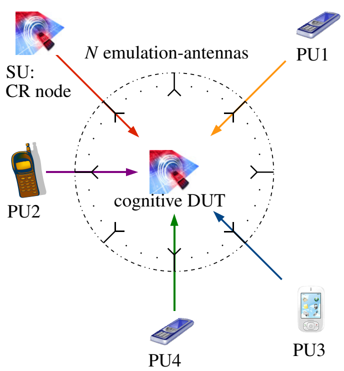

Figure 2: Example scenario for test level 1 (only LOS).

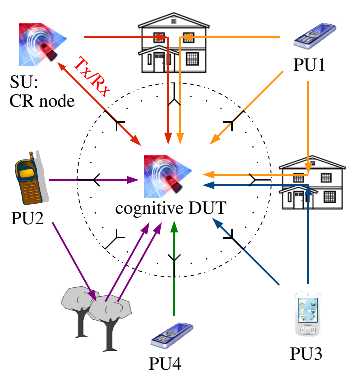

Figure 3: Example scenario for test level 4 (LOS & multipath).

Table 1: Overview of the test levels.

radio channels	test focus on	
	observe	*observe & act*
only LOS	test level 1	test level 3
LOS & multipath	test level 2	test level 4

4 Proof of principle

This section presents proof-of-principle experiments on test level 1, however, without distinction between PU and SU. The motivation behind the experiment was to discover the challenges of OTA testing and the use of a directional antenna array for the CR node. With the initial OTA testbed, we are able to test directional spectrum sensing, that is, to detect different power spectral densities (PSDs) impinging from different directions. The test setup is composed of eight emulation-antennas in a circular arrangement, a signal generator, several oscillators, power amplifiers, and a fading emulator. Multiple mixers of the fading emulator were used to up-convert a constant multi-carrier signal of 9 MHz bandwidth to three frequency bands, namely 0.9 GHz, 1.8 GHz and 2.45 GHz. In this way, eight (primary) user signals were generated. A sketch of the used frequency range of each user signal and its allocation to an emulation-antenna is given in figure 4. Figure 5 shows a photograph of the setup in the anechoic chamber. As cognitive DUT we used a custom-built sectorized antenna, that can operate in the three aforementioned frequency bands, connected to a commonly available SDR platform, USRP2 [5]. For the spectrum sensing in each direction, an energy detection algorithm was implemented. It is worth mentioning that all emulated users were active during the measurements. Furthermore, the orientation of the cognitive DUT to the emulation-antennas was changed in 45° steps. As a result, the sensed PSDs at the three different antenna sectors varied, depending on the orientation. In the post-processing, the possibility of secondary use in any frequency band and sector was assessed – for each orientation. The results showed, that the PSD of each received user signal differed, depending on the direction or rather the antenna sector. The maximum crosstalk suppression between the antenna sectors was about 20 dB for a user on boresight of one of the sectors. By comparison of the sensed PSDs in the three sectors, the cognitive device can coarsely determine in which direction a PU is located. Consequently, an opportunistic choice of the sectors and the frequencies for secondary use

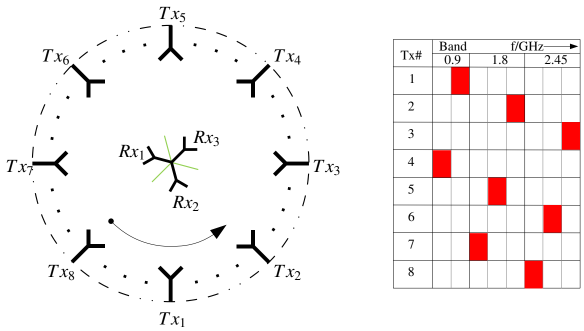

Figure 4: Sketch of the eight user signals and their allocation to the emulation-antennas. The lab version of the DUT antenna has 3 sectors, separated with absorbers (green line).

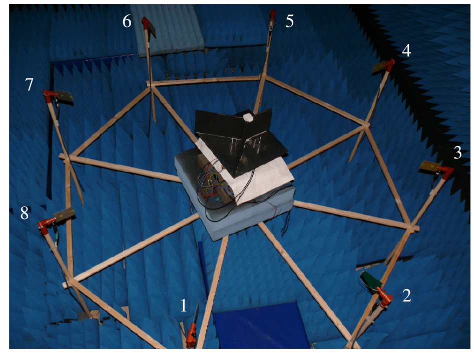

Figure 5: Photograph of the OTA test setup in the anechoic chamber of Ilmenau University of Technology.

can be taken. Hence, by exploiting the direction as additional radio resource, a multiple use of frequencies could be achieved. Detailed results on this experiment will be given in a further paper. With regard to the testbed, it must be pointed out that the calibration is essential in OTA testing. Hereby, the sum of insertion and path loss has to be set to an equal value for each emulation channel. This can be done by measuring the forward transmission coefficient with a network analyser and an omnidirectional reference antenna in the location of the DUT. Moreover, RF impairments in the measuring arrangement should be avoided or reduced by appropriate signal processing.

5 Conclusion

An over-the-air test strategy was proposed for performance evaluation of cognitive radio nodes. Particularities of such a testing are the inclusion of the real antenna system of the node and the emulation of an authentic radio environment. This enables realistic tests, especially of devices that exploit the spatial structure of the radio channel. A proof of principle was demonstrated successfully. However, further investigations are required to exploit and demonstrate the full potential of this concept. Future work will be on implementation of PUs and SUs on test level 1, as well as higher test levels.

6 Acknowledgements

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