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Cognitive Radio – A Necessity for Spectrum Pooling

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The demand for wireless communication capacities is continuously growing. This is especially true for cellular and also for wireless local area networks (WLANs). The options for increasing capacity are to apply advanced signal processing technologies in "traditional" frequency regions or to open up higher frequency ranges. The second alternative, however, is somewhat difficult in mobile applications because the radio wave propagation becomes nastier with increasing frequency.

Recent measurements (e.g. in New York City [1]) indicate that the average spectrum utilization for frequencies below 6 GHz is in the order of 15%. That is that a huge capacity gain for these frequencies should be possible with the implementation of advanced signal processing technologies. One of them, spectrum pooling, is the starting point of this talk.

This talk discusses the spectrum pooling approach [2] that enables public access to already licensed frequency bands. The notion *spectrum pool* basically represents the idea of merging spectral ranges from different spectrum owners (military, trunked radio, etc.) into a common pool. It reflects the need for a completely new way of spectrum allocation. From this common spectrum pool hosted by the so-called licensed system, public rental users may temporarily rent spectral resources during idle periods of licensed users. The basic proposition is that the licensed system does not need to be changed. The installed hardware can be operated like there was no other system present in the same frequency range. This approach kills two birds with one stone. Rental users obtain access to spectral ranges they have not yet been allowed to use, and the actual license owners can tap new sources of revenue for a good they have not been using intensively anyway. A multitude of juridical and economic consequences occurs when implementing the idea of spectrum pooling in a real system. Concerning the regulatory aspects of spectrum pooling, one must say that regulators are well aware of the fact that public mobile radio spectrum is falling short, and considerations toward secondary use of already licensed frequency bands are going on. After all, it is a political question whether this new concept will be admitted. However, once the technical obstacles are overcome and the feasibility of spectrum pooling is proven, politics cannot refuse this idea. The economic questions that must be answered are currently subject to scientific investigations in research projects funded by the European Union involving a variety of topnotch industrial partners and leading edge research institutions. Despite all the interesting juridical and economic aspects, this talk focuses on the technical challenges spectrum pooling implies. First, a short introduction to the general structure of a spectrum pooling transceiver and the utilized orthogonal frequency-division multiplexing (OFDM) modulation scheme on the rental user side is given, which is essential to understanding the remainder of this contribution. After investigations of spectrum pooling, specific tasks in the physical layer, and problems and their solutions concerning the MAC layer of the rental system are presented.

Obviously, receivers in a spectrum pooling rental system must be able to detect temporarily idle frequencies very fast. This is a typical task for a cognitive radio that comes into the game when considering what follows: Today spectrum is regulated by governmental agencies like the Federal Communications Commission (FCC) in the US or the Bundesnetzagentur (BNetzA) in Germany. Presently, spectrum is assigned to users or licensed to them on a long term basis normally for huge regions like whole countries. Doing so, resources are wasted. It is our vision that spectrum within a large frequency range (that has to be defined by governments) becomes free for open access such that resources are assigned only as long as they are needed by the user. Moreover, spectrum is assigned on a regional basis obeying that stations using identical frequencies cannot interfere. Already existing examples for self regulation of networks are WLANs (IEEE 802.11) or ultra wide band (UWB) systems.

A *cognitive radio (CR)* [3] is a software defined radio (SDR) that additionally senses its environment, tracks changes and reacts upon its findings. A CR is an autonomous unit in a communications environment. In order to use the spectral resource most efficiently, it has to

- be aware of its location
- be interference sensitive
- comply with some communications etiquette
- be fair against other users
- keep its owner informed

In order to handle its tasks, a CR carries location sensors (i.e. GPS or Galileo) in order to determine its own location. It has to monitor its spectral environment, e.g. by employing a broadband fast Fourier transform (FFT). To track its location or the spectral environment‘s development, it has to use appropriate learning and reasoning algorithms. Most important, CRs should be polite to other spectrum users. I.e. it has to compromise its own demands with the demands of other users, most probably making decisions in a competitive environment using the results of game theory. Last but not least, a CR should contact his owner via a highly sophisticated man-machine-interface. So the CR’s user may be kept informed about its actions.

This talk is intended review past investigations on spectrum pooling and to present the work concerning CR and advanced spectrum usage currently under way at the Institut für Nachrichtentechnik of the Universität Karlsruhe (TH).

[1] Mark McHenry, Dan McCloskey: *New York City Spectrum Occupancy Measurements September 2004.* Shared Spectrum Company, 8133 Leesburg Pike, Suite 220, Vienna, VA 22182, 2004

[2] Timo A. Weiss, Friedrich K. Jondral: *Spectrum Pooling: An Innovative Strategy for the Enhancement of Spectrum Efficiency*. IEEE Communications Magazine, March 2004, Radio Communications Supplement, pp. S8 - S14

[3] Friedrich K. Jondral: *Software Defined-Radio – Basics and Evolution to Cognitive Radio.* Invited paper, EURASIP Journal on Wireless Communications and Networking, 2005, No. 3, pp. 275 - 283