Field Research and Evolution to Cognitive Radio

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Outline

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  - Brief history
  - Enabling technologies
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- **Cognitive Radio and Cognitive Networks**
  - Brief history
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  - Applications
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Introduction

What's the SDR?

- Software-Defined Radio (SDR) refers to the technology wherein software modules running on a hardware platform consisting of DSPs, programmable HW and general purpose microprocessors are used to implement radio functions, such as generation of transmitted signal (modulation) at transmitter and tuning/detection of received radio signal (demodulation) at receiver.

Early History of SDR

- 1991 - Mitola described the SDR architecture principles in a paper, "*Software Radio: Survey, Critical Analysis and Future Directions*".
- 1990-1995 –*SpeakEasy I project* by U.S. DARPA produced a demonstration of a software defined radio that could operate from 2 MHz to 2 GHz.
- 1996 - Creation of the 'SDR Forum', that became 'Wireless Innovation Forum' in 2010.
- 1998 - *SpeakEasy II project* by U.S. DARPA: produced a smaller and cheaper radio with a 4 MHz to 400 MHz range. The project was the first known to use FPGAs for digital processing of radio data.

History of SDR

- 2001 - GNU Radio was established (founded by Eric Blossom and funded by John Gilmore)
- 2004 - FCC first approval of a commercial SDR
- 2006 – TI + Xilinx + Nutaq alliance to create the first completely integrated, stand-alone SDR development platform. It was equipped with an ARM, a DSP, an FPGA, and a front-end tunable from 200 MHz to 1 GHz (other ranges came later).
- 2009 - First commercial single-chip RF front-end (LMS6002) by Lime Microsystems, a radio frequency integrated circuit (RFIC) tunable between 400 MHz and 4 GHz, up to 28 MHz of bandwidth and a selectable baseband filter bank.

SDR: some early motivations

- In the event of 9/11 twin-towers, the New York City police and fire departments desperately needed to communicate with one another, but their radios could not interoperate.
- Prior to 9/11, the US armed forces had recognized a similar problem with legacy radio systems used by different armed services branches and started JTRS (Joint Tactical Radio System) program.
- **JTRS** has been a major push for SDR and is responsible for the creation of the **Software Communication Architecture** (SCA) Operating Environment (OE) standard.

SDR: Present Motivations

Issues

Evolution of PHY layer protocol standards (3G, 4G and 5G)

Reconfigurable handset and base stations

Interoperability across multiple networks

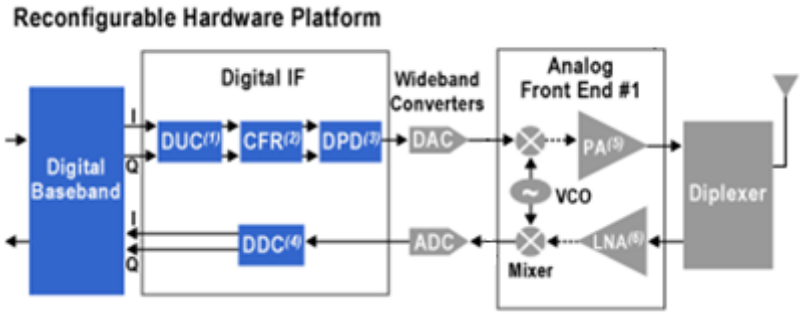
Context

SDR provides a solution for a broad range of communications and devices including:

- cellular base station and handsets
- commercial and military satellites
- military radios
- public safety
- wireless LAN/WAN
- automotive

SDR: enabling technologies

- Key components:
  - wideband linear power amplifiers
  - high-speed, spurious-free high dynamic range analog-to-digital (ADC) and digital-to-analog (DAC) converters
  - digital signal processors (DSP)
  - field programmable gate arrays (FPGA's)
  - high-speed digital signal processing devices such as application specific integrated circuits (ASIC's)
  - software modules



SDR: challenges

- The current implementations of SDR products suffer from limitations that preclude development of a practical and widely deployed handheld SDR.
- Challenges including reduction of:
  - power consumption
  - size
  - weight
  - implementation costs of practical handheld SDR devices.

SDR: evolutions

- GNU Radio is a free software development toolkit that provides signal processing blocks to implement software-defined radios and signal processing systems. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. It is widely used both in academic and commercial environments to support wireless communications research and real-world radio systems.

GNU Radio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

SDR: evolutions

- OSSIE is an open source Software Defined Radio (SDR) framework developed at Wireless Virginia Tech.
  Project's key elements:
  - based on the JTRS Software Communications Architecture (SCA);
  - a set of tools for rapid development of SDR components and waveforms
  - an evolving library of pre-built components and waveforms

- REDHAWK is an open software-defined radio (SDR) framework designed to support the development, deployment, and management of real-time software radio applications.

  Project's key elements:
  - tools to allow development and testing of software modules
  - Integration of modules into "Waveform Applications" running on a single computer or multiple-computer network .

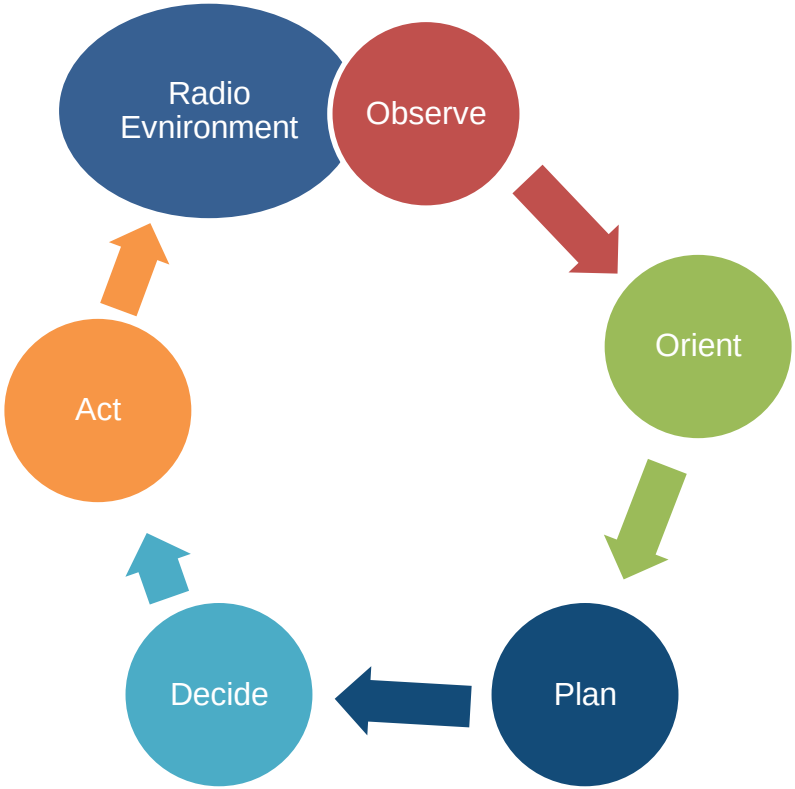
➢ **SDR: an enabling technology for CR**

What is Cognitive Radio?

- A cognitive radio is an intelligent radio that can be programmed and configured dynamically based on the awareness of the surrounding environment (e.g. best available wireless channels)
- Such a radio automatically gets environment data and accordingly changes its transmission and/or reception parameters to allow more efficient wireless communications

Brief History of Cognitive Radio (and Networks)

- 1998 - The concept of cognitive radio was first proposed by Joseph Mitola III at the Royal Institute of Technology in Stockholm.
- 2001 - IBM instigated the introduction of a cognition cycle into networks.
- 2005 – Clark provide a definition of cognitive network and Haykin published a seminal paper on CR
- 2008 – Concept of *large scale cognitive network* was further made by Song.

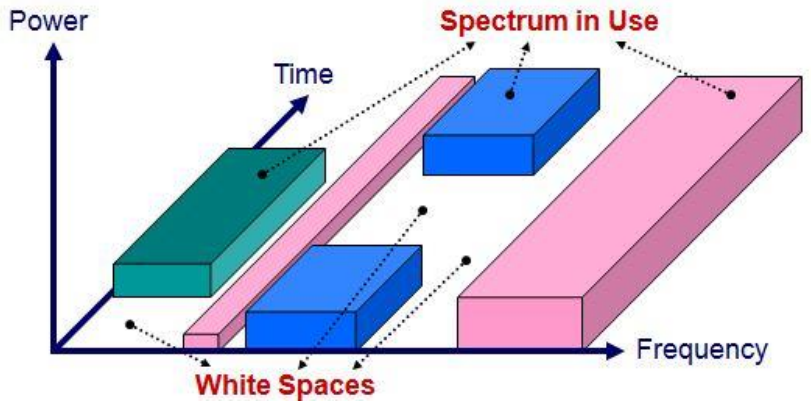


CR: main implementation alternatives

- *Full Cognitive Radio*: every possible parameter observable by a wireless node (or network) should be included
- *Spectrum-Sensing Cognitive Radio*: only the radio-frequency spectrum is considered.
- *Licensed-Band Cognitive Radio*: capable of using bands assigned to licensed operators (i.e. IEEE 802.22 operating on unused TV channels)
- *Unlicensed-Band Cognitive Radio*: which can only utilize unlicensed parts of the radio frequency (RF) spectrum (i.e. IEEE 802.15 focusing on the coexistence of IEEE 802.11 and Bluetooth)

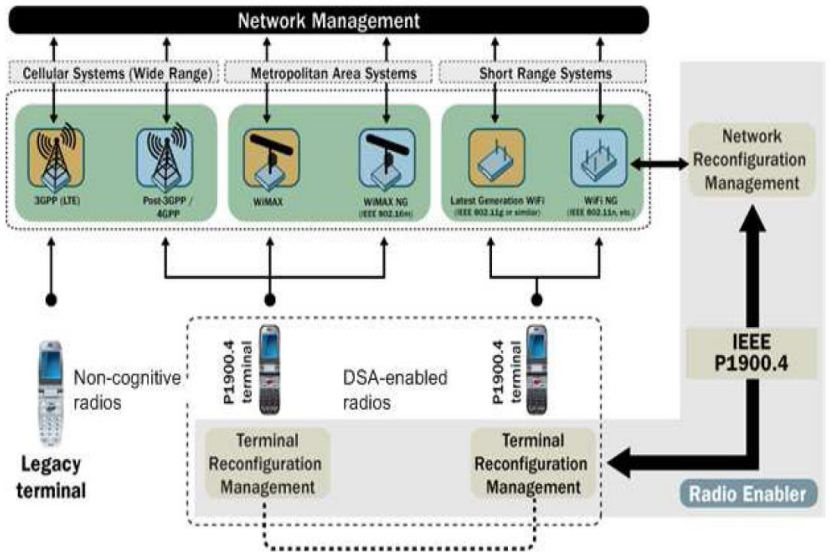
CR: spectrum access strategies

- *Spectrum mobility*: cognitive-radio platforms can change their frequency of operation (DSA)
- *Spectrum sharing*: cognitive-radio platforms share the spectrum bands with licensed-band users (with limitations)
- *Sensing-based Spectrum sharing*: cognitive radio platforms first listen to the spectrum allocated to the licensed users to detect the state of the licensed users. Based on the detection results, cognitive radio platforms decide their transmission strategies



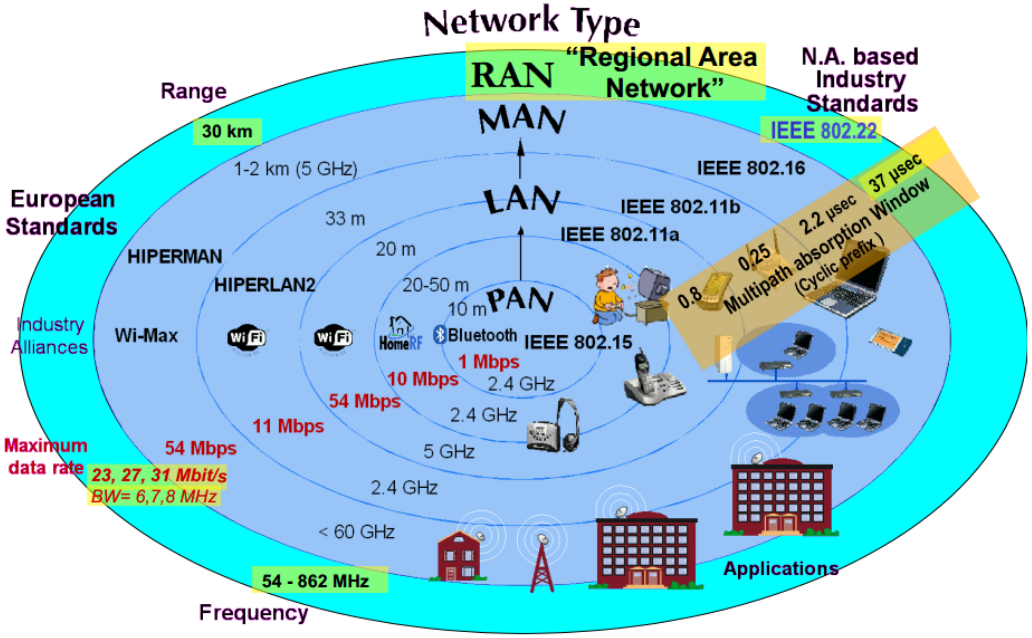
CR standards – DySPAN SCC41 P1900.4

- Architectural concepts and specifications for network management among incompatible wireless networks
- Network management for dynamic spectrum access among 3G/4G, WiFi, and WiMax networks.



CR standards - IEEE802.22 WRAN

- IEEE 802.22 is a standard for Wireless Regional Area Network (WRAN) using white TV spaces
- The goal: bring broadband access to hard-to-reach, low-density population areas, typical of rural environments and developing countries



IEEE802.22 WRAN key features

- License-exempt equipment
- Point-to-multipoint network topology:
  - Base station provides service up to 512 (fixed or portable) terminals and controls all their RF characteristics (“master-slave”)
  - Base station connected to the Internet through a backhaul
- CR capabilities to avoid interference to broadcast incumbents and other WRAN systems:
  - Access to databases
  - RF sensing
- Main features:
  - 100 km range of coverage on VHF and UHF bands.
  - 7 to 22Mbps per channel for transmissions up to 30km.

CR: key technologies

- SDR as an enabling technology
- CR key techniques to opportunistically operate in the underutilized spectral bands:
  - *Radio front-end design* including **SDR** components
  - *Baseband Spectral Shaping*
    - e.g. as specified by FCC, only the cognitive devices transmitting signals with an Adjacent-Channel power-Leakage Ratio (ACLR) no larger than −72.8 dB may operate over TVWS.
  - *Spectrum Sensing*: Energy Detection and Geo-location Databases
  - *Cognitive Engine:* adaptive decisions of the radio transmission parameters based on the environmental conditions and capabilities of the transceiver:
    - Mathematical Optimization
    - Game Theory
    - Machine Learning
  - *Location Awareness*

CR: current status

- *Frequency Range:* focused on the locally TVWS and in general below 5GHz.
- *Cell Size*: small cells
- *Localization of CR devices*: to exploit Geolocation Databases both indoor and outdoor localization in the meter range in combination with Spectrum-sensing
- *Relevant Players in the CR Value Chain*:
  - Chip manufacturers
  - Software suppliers
  - Device manufacturers
  - Network operators

CR applications: WhiteFi

- *WhiteFi* (or SuperWi-Fi) means wireless networking using TVWS especially for broadband wireless
- Suited by the IEEE 802.22 and 802.11af standards.
- NICT in Japan recently announced the world's first 802.11af and 802.22 prototypes, but no off-the-shelf product on the market yet available.
- WhiteFi networks trialed and deployed by companies and universities (Microsoft, Google, Adaptrum and Rice University, etc.)
  - mainly using GDBs for obtaining the vital knowledge about the locally available white spaces.

CR applications: CISCO CleanAir

- The CleanAir technology developed by Cisco is aimed at creating a spectrum-aware, selfhealing and self-optimizing wireless network which can mitigate interference and provide performance protection for 802.11n networks.

CR applications: Beyond 4G

- Standardization of CR in 4G LTE-A is at the very beginning phase, however pioneer research and prototyping project has been conducted:
  - CoMoRa* project is aimed at innovating “Beyond 4G systems” with advanced spectrum awareness, spectrum management and cognitive engine.
  - EU FP7 ABSOLUTE project applies CR to a wireless network for the scenarios of disaster relief and unexpected events, being mainly built upon LTE-A technology.
  - CORASMA^{+} project for CR application to tactical environments

- funded by the German Federal Ministry of Education and Research
- funded by the European Defense Agency (EDA)

Software-defined networks (SDN)

- Early stage of study and definition
- Perspectives for 5G systems and beyond
- Aims at the management of network functionalities and services by centralized SW modules (e.g. routing, network topology, …)
- Adaptive, programmable, reconfigurable network elements
- Suitable for the high-capacity, fast-adaptive, high-performance requirements of next generation networks
- The SDN architecture should be:
  - All programmable
  - Agile
  - Centrally managed
  - Programmatically configured
  - Open standards-based and vendor-neutral

Cognitive Radio: future

- In the following decade the “shift-to-market” activity of CR product and CR based services will boost wireless communications.
- Open issues to be solved:
  - efficient spectrum management systems
  - real time implementation
  - CR security
  - CR national and international regulations

THANKS FOR YOUR ATTENTION.

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