Cognitive Radios (CR)
Potential Regulatory Issues

Dirk-Oliver von der Emden
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What Is the Object of Our Curiosity?

Cognition

→ No unique definition

• Great functions of the mind
• Mental processes of acquisition of knowledge

« Cognitive » radio

→ No unique definition

• “Aware”
• “Adapting”
• “Learning”
• In a single word: “Intelligent”…

My emotions are the product of fantastic algorithms!

Is it a cognitive radio?
Device-related Aspects

Importance of Software-defined Radio (SDR)

- **Very likely Cognitive Radio will be based on SDR**
  - But: a SDR is not necessarily a CR [criteria: “intelligence”]
- SDR: Radios whose operating parameters are **generated by software** (e.g. frequency range, modulation type)

![Diagram of Software-Defined Radio (SDR)]
Advantage: Reconfigurability

- **Flexible implementation of heterogeneous “standards”**
  - Several standards operate on same components (RAM, interfaces, ....)
  - No or small increase of hardware costs for additional standards

- **Preparedness for future “standards”**
  - Software for new standard downloadable
  - Easy migration to modified/extended standards
“Cognitive” Spectrum Access
As Presently Envisaged

- **Secondary, Underlay Use**
  Heterogeneous systems use the same spectrum as primary systems on a non-interference/non-protection basis

- **Mesh / Ad Hoc Networks**
  Cooperative relaying
  - self-organising
  - self-healing
  - self-

  **not necess. for free!**

**Software-Defined Radio SDR**

**“Cognitive” Spectrum Access**

**Regulatory: R&TTE**

**Regulatory: Spectrum**

**Wrap-Up**

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Cognitive Radios and Networks
Radio Resource Management

Varying locations of “intelligence” in relation with

- **Information gathering** (discovery)
- **Identification** (available access schemes, spectrum resources)
- **Decision-making** concerning spectrum usage

<table>
<thead>
<tr>
<th>Dynamic Spectrum Assignment</th>
<th>Spectrum Access Negotiation</th>
<th>Opportunistic Spectrum Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;intelligence&quot;</td>
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</tr>
<tr>
<td>Network centric</td>
<td>Distributed</td>
<td>Centralised</td>
</tr>
<tr>
<td>Collaborative</td>
<td>Individual</td>
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**Summary**

- **Software-Defined Radio SDR**
- **“Cognitive” Spectrum Access**
- **Regulatory: R&TTE**
- **Regulatory: Spectrum**
- **Wrap-Up**
Information Gathering & Identification

Sensors, “Beacons”, Databases, …

- **Autonomous sensing and deciding very delicate**
  - Amongst others: “Hidden node” problem

- **Assistance: Cognitive Pilot Channel (CPC) or equivalent**
  - Lowers noticeably risks of interference
    - Centralisation of sensing, mapping, deciding, …
  - Reins in costs of terminals
    - Limited sensing capabilities sufficient in terminals
  - Saves time and battery energy
    - Curtails consuming spectrum scanning procedures (search of other users, access technologies,…)
  - Facilitates terminal reconfiguration in heterogeneous wireless environments
    - Over-the-air download of updated software possible

- **Occurrence of substantial signaling overhead**
## CR in Comparison with SDR

**SDR Is Key in Order to Develop CR**

<table>
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<tr>
<th><strong>Software-defined Radio</strong></th>
<th><strong>Cognitive radio</strong></th>
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<tbody>
<tr>
<td>• Dynamic support of multiple variable systems, protocols and interfaces</td>
<td>• <em>Autonomous</em> discovery and development of new radio access technologies</td>
</tr>
<tr>
<td>• Interface with diverse systems</td>
<td>• <em>Autonomous</em> negotiation with available networks and selection of most appropriate access technology</td>
</tr>
<tr>
<td>• Wide range of services with varying QoS</td>
<td>• Adjusting operations to meet QoS required by application</td>
</tr>
<tr>
<td>• Many upgrade mechanisms</td>
<td>• Further upgrade mechanisms</td>
</tr>
<tr>
<td>• <strong>External and centralised</strong> (e.g. firmware over-the-air)</td>
<td>• <strong>Internal</strong> (<em>autonomous</em>)</td>
</tr>
<tr>
<td>• <strong>Individual</strong> (e.g. OSS)</td>
<td>• <strong>Collaborative</strong></td>
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</table>
Key Points
From My Perspective

• **SDR: Presently mainly niche products**
  - Today potentially attractive only for long life time radios
  - Military at vanguard of SDR usage
  - ETSI and IEEE established groups addressing reconfigurable radio systems (RRS)

• **CR: Presently at the stage of models, concepts**
  - Wider potential than just “white space devices” (WSD)
  - Vast efforts in Europe at the level of research
    - COST IC0902 and IC0905, FP7, E³, ARAGORN, & many more…
  - Phobia of incumbent users vs. CR concepts [secondary use]
  - Dubiety on potential commercial mass applications
  - Goodwill from spectrum management authorities
Potential Regulatory Issues

Overview

• **Devices’ conformity & Market access (R&TTE)**
  • Conditions for conformity
  • Interoperability
  • Standardisation
  • Market surveillance
  • Liability, responsibility

• **Spectrum access**
  • Radio interface specifications
  • Spectrum Trading

• **Privacy of telecommunication & data protection**

• **Lawful interception & data retention**
Market Access of SDR/CR in Europe
Analogy Possible With Cars?

- Use intended by manufacturer when originally placed on the market
- "Reconfigured" version with modified software (and hardware)

No \rightarrow "Pre-market" control by car authorities: Type Approval
Potential Regulatory Issues Resulting from Reconfigurability

Present radio devices  SDR / CR

Equipment

ASIC*
* Application Specific Integrated Circuit

Soft- and middleware

OS*
* Operating System

General-purpose Processor

Some users may start to manipulate these
### Material, Essential Requirements

- EMC
- Electric safety
- Efficient use of spectrum

### Formal, Administrative Requirements

- Application of conformity assessment procedure
- Markings (CE, class identifier, etc.)
- Inscriptions (type, serial number, etc.)
- Notification
- User information (intended use, declaration of conformity, etc.)

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**Additional requirements needed for reconfigurable equipments?**

**Application to software products workable?**
Additional Essential Requirements?
For Reconfigurable Radio Equipment

• **Interoperability?**
  - Esp. when hard- and software marketed by separate entities
  - Standards for software architecture
    - Open platforms
    - Published APIs

• **Network, equipment integrity?**
  - Protection against unauthorised programming (e.g. hacking)
  - Recording of configuration history ("Reconfiguration Controller")
  - Autonomous downloading of updated software

• **Others?**
Interoperability
„Standardisability“ of Interfaces of CR/SDR?

- Decision of the Commission required for interoperability to be essential requirement
  Article 3, para. 3, lit. a), R&TTE Directive 1999/5/EC
  - Justification for such a decision?
- Effectiveness?
  References to standards in RIS only informative
  - Merits of making some references mandatory?
- Which interfaces of SDR/CR should be covered?
  - Vertical interoperability
    user equip. ⇔ network
  - Horizontal interoperability
    user equip. ⇔ user equip.
Software with User-modifiable Code & Open-Source Software (OSS)


- No hindrance on OSS developers not affiliated with device manufacturers to work on their software
- CR devices using OSS-based software platforms could also pass FCC certification

OSS makes difficult to:

- Identify “author” of non-conform product (software)
- Establish when modifications of software leading to irregular situation were made

→ Vain to enact regulation fixing responsibilities in case of non-compliance of SDR/CR equipment?
Key Points
From My Perspective

• For SDR or CR, return to type-approval not an option
• Additional, different **essential, material requirements**?
• Additional, different **administrative, formal requirements**?
  • Less stringent provisions for SDR/CR devices “notably modified” (updated) by manufacturer or network operator?
• **Review of repartition of responsibilities between actors?** (Relevant only if reconfiguration using third party software is permitted)
  • Responsibilities of equipment, hardware manufacturers established relatively clearly
  • What about radio software developers (IT industry)?
    • Acceptance of responsibilities for their products similar to manufacturers?
    • Enforceability by market surveillance authorities?
Spectrum Access by Cognitive Radios
“It’s all about getting a grip on interference”

Again a shaky analogy of mine?
Spectrum Access
Authorisation Regimes for Radio Spectrum Use

“Individual”
authorisation

„General“
authorisation

Conditions of use associated to authorisations

Radio interface specifications (RIS)

Technical conditions

Operational conditions

Individual operational conditions

Mesh network under control of an operator (licensee)

- Underlay applications
- Self-managed mesh network (secondary or primary status)
Technical and Operational Conditions
Detailed Implementation Rules Needed

- **“Dirk’s Conjecture”**: The regulatory principles of present-day radio-regulatory framework can accommodate agile radio systems

  - NB₁: Requires specific rules on spectrum access conditions
    → **Radio Interface Specifications (RIS)**

  - NB₂: Maybe even too supple…
    → “Technology neutrality” paradigm

- **Secondary Spectrum Use**
  - **”Detection”**
    → Criteria ensuring protection of existing services
    - Without imposing too constraining conditions on industry of agile radio systems
  - **”Aggregation”**: cap-levels?

- **Mesh / Ad hoc Networks**
  - **“Dialogue mechanisms”**
    → Control and signalisation in co-operative systems
    → Co-operation between systems
    Interoperability prescriptions?
Market-based Spectrum Access

Spectrum Trading

- **Spectrum leasing for underlay usage**
  - Primary spectrum users lease usage rights to secondary users
  - Minimal regulatory constraints, maximal flexibility (both for primary and secondary users)
    - Users as free as possible in designing rights to be traded
  - Negotiations may result in *willingness to share* by primary user in favour of secondary user
    - Primary user → Appreciation of amount of “interference” that can be tolerated at which location, time, and in which frequency channels (etc.)
    - Secondary user → Definition of wanted QoS (etc.)
    - Existing overlap? Agreement on price?
Market-based Spectrum Access
Capacity Renting, Brokering

• Renting capacity of other users’ devices for relaying in mesh/ad hoc networks
  • Not spectrum trading *stricto sensu*
  • Spectrum trading non-sense in license-exempt bands
  • Countless modalities imaginable for implementing capacity renting in mesh networks
  • Any need for regulation of negotiations for relaying?

• Establishing brokerage agents or institutions?
  • Primary users also bid in order to access spectrum?
  • Third party spectrum manager maximises usage (= revenue?) of entrusted resource
    • = most efficient balance between CR users’ rights and legacy users’ rights?
Key Points

From My Perspective

• Competition of “standards” unavoidable
• In short/medium term: Services with higher regulatory status not unquestionably protected by sensing alone
• Alleviation by CPC, databases, …
  • One core aspect: quality of data (actuality, precision, etc.)
  • If incompatible technologies: any co-ordination?
  • Mandatory harmonised standard ensuring interoperability?
• Spectrum trading *might* be a major facilitator for SDR/CR
  • What are pre-requisites for instant & short-term trading?
  • Will payment lead primary users to moderate their protection claims?
  • Special design of spectrum pricing or auctions in order to play complementary role?
Technological Requirements
Important Technical Progresses Still Required

With a view to mass-market

- **Processors** (CPU: *Central Processing Unit*)
  Replacing nowadays ASIC

- **Algorithms**
  - For handhelds’ CPUs for dynamic and opportunistic access to spectrum
  - For auto-organising networks (*signaling architectures, etc.*)
  - Energetic efficiency of algorithms

- **Electric Accumulators** (batteries)
  - Power consumption

- **Miniaturisation**

Last but not least

- **Develop a viable business model...**
## Concerns of Interested Parties

### Relating to the Introduction of CR

<table>
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<tr>
<th>Regulators</th>
<th>Users</th>
<th>Mesh Netw. Operat.</th>
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<tbody>
<tr>
<td>• Not critical if network controls equipment</td>
<td>• Interoperability</td>
<td>• Network integrity and security</td>
</tr>
<tr>
<td>• Telecommunications’ Privacy &amp; data protection</td>
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<td>• Number of users impacts on required bandwidth</td>
</tr>
<tr>
<td>• Efficiency of spectrum use due to signaling &amp; addressing overhead</td>
<td>• Battery life</td>
<td>• Business model</td>
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**Network**
- Establishing conditions guaranteeing minimised risks of interference
- Difficult future refarming
- Consistency with international obligations

**Underlay**
- [Primary users]
  - Aggregate interference
  - Shadowing, Hidden node
  - Sensing may not recognise new systems
Implications for Administrations
Market Surveillance & Radio Monitoring

• **Substantial challenge for radio monitoring**
  - Difficulty to observe, identify, and determine in a timely manner a source of unlawful interference

• **Considering placing more responsibility on spectrum users?**
  In case of
  - *absence of conformity* (essential requirements)
  - *non conform use* of SDR/CR equipments (access to spectrum)
Fields of Investigation for WG RA
Speaker’s Selection

• SDR/CR-preparedness of
  • Equipment conformance regulation?
  • RIS model?
  • Responsibility ascription regulation?
    • Increased facility and lower cost of manipulating equipment reduces manufacturers’ or network operator’s control

• Elaborate regulatory measures applicable to SDR/CR
  • Facilitating location of source of interference?
  • Facilitating in due course refarming? (esp. license-exempt)
  • Mandating upgrading faculty to future standards, spectrum rules, etc.?
  • Correcting deficiencies in relation with spectrum trading?

• Always: Regulation should be enabler for new technologies
Thank You for Your Attention

“Could you explain that again in real words?”