The E3 Architecture and Solutions for Cognitive Radio Networks

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Presentation outline

- E3 Overview
- Architecture
- Self-Organization/Self-Optimization
- Flexible Use of Spectrum
- Prototyping Environment
- Cognition Enablers
- Standardization of Cognitive Systems
- Conclusions
E³ is an European Project on End-to-End-Efficiency under the 7th Framework Program of the European Commission, addressing the core of the strategic objective "The Network of the Future"

**Top Level Objectives:**
- **Cognitive Radio System design**
- **Gradual, non-disruptive evolution of wireless networks**
- **Increased efficiency of wireless network operations**

**Project Duration:**
End-to End Efficiency

E³ - Partners

Network operators (4)

Alcatel-Lucent
Bell Labs Germany
project coordinator

Equipment manufacturers (6)

Telefonica

Operators

Deutsche Telekom Laboratories

Ericsson

Thales

Nokia

NEC

Toshiba

Bell Labs Germany project coordinator

Academia / research institutes (8)

BUPT

Vrije Universiteit Brussel

UNIVERSITY OF SURREY

IDATE Consulting & Research

UNIVERSITY OF AUCKLAND

Academia / research institutes (8)
Cognitive Radio Aspects: Evolution

- Introducing Reconfigurable, Cognitive Systems in the B3G world:
- Evolution of B3G systems to Cognitive Radio Systems
- Improve utilisation of spectrum and radio resources
  - Dynamic Spectrum Management
  - Support of heterogeneous standards
  - More efficient Joint Radio Resource Management (Short term)
- Reconfigurable Base Stations and Reconfigurable Terminals
- Self-Management and Self-Optimisation of
  - Radio Network Infrastructure
  - Cognitive Devices
- Cognition Support Mechanisms
  - Cognitive Pilot Channel, Spectrum Sensing
The pillars of the architecture

- AEM - Autonomic Entity Management
- CCR - Cognitive Control Radio
- CPC - Cognitive Pilot Channel
- SS - Spectrum Sensing
- RCM - Reconfiguration Control Module
- DSM - Dynamic Spectrum Management
- DSNPM - Dynamic Self-organizing Network Planning & Management
- Self-x-for-RAN - Self-x for Radio Access Networks
- JRRM - Joint Radio Resource Management
- RRM - Radio Resource Management

Self-x pattern applies
Functional Architecture (FA)
Single Operator Case

Terminal

RCM Reconfiguration Control Module

Self-x for RAN Supporting functionalities

JRRM Joint Radio Resource Management

RAT 1  RAT 2  ...  RAT n

Network (Operator)

DSM Dynamic Spectrum Management

DSNPM Dynamic Self-organising Network Planning and Management

Self-x for RAN Self-organizing Network functionalities

RCM Reconfiguration Control Module

RAT 1  RAT 2  ...  RAT n

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Functional Architecture (FA) Multi Operator Case
Heterogeneous Wireless System and Functional Building Blocks

- AEM
- JRRM
- CPC
- SS
- RCM

- Multi-Receiver Terminal
- Single-Receiver Terminal, reconfigurable

FBS: Flexible Base Station

Radio Access
- DSM
- DSNPM
- Self-x (RAN)
- JRRM
- CPC
- SS
- RCM

Operation & Management
- Core Network
- PCRF
- Operation & Management
- FBS

Core Network
- SAE Serving Gateway
- SAE PDN Gateway
- HSS
- MME
- DSNPM
- Self-x (RAN)
- RCM
- CPC
- ANDSF
- Self-x (RAN)

WLAN
- ePDG
- FBS: Flexible Base Station
Self-Management and Self-Optimisation of Cognitive Systems:

- Awareness of user, device and context information
- Policies derivation
- Decision making
- Reconfiguration
- Learning

Cognitive Systems determine and configure their operation based on the knowledge and experience obtained through learning,

- In a reactive manner, i.e. responding to the detection of problematic situations
- Proactively to prevent issues undermining the optimal system function

Simulation of new approaches & algorithms

Recommendations for service-, network providers & equipment manufacturers
Self-Organization of Networks (2/4)

Self-X: Self-configuration, Self-optimisation, self-healing

⇒ for single-RAT networks as well as heterogeneous networks
⇒ Spectrum selection, inter-cell interference coordination
⇒ Cell-outage compensation, cell self-reconfiguration
⇒ Handover optimisation, load balancing

deployment of new cells & nodes  →  self-configuration  →  operational mode

self-optimisation

Performance monitoring

optimised radio parameters
Self-Organization of Networks (3/4)

Input:
- **Context**: traffic, mobility, interference, element status
  - Change of element status, e.g., fault of some component like TRX → trigger for self-healing mechanisms
- **Profiles**: equipment, application, user requirements and preferences
- **Policies**: optimization objectives, strategies, constraints

Optimization mechanisms:
- **Algorithms** for various time scales, optimal or near-optimal
- **Short time scale**: greedy, online
- **Mid-term**: simulated-annealing, taboo search, genetic algorithms
Output:

- Configuration at various levels e.g.:
  - RAT per transceiver
  - Spectrum per transceiver
  - QoS level determination per user class

Learning:

- Contexts encountered in time space
- Solutions applied and efficiency

Impact:

- Optimal QoS, operational efficiency, automation of tasks, minimization of human involvement, reduction of operational expenditure (OPEX)
Flexible use of spectrum

- Spectrum management for optimal spectrum usage
  - Dynamic Spectrum Allocation (DSA):
    - Spectrum control in the network
    - Medium/long term radio resource optimisation
  - Dynamic Spectrum Selection (DSS):
    - Spectrum control entity in the terminal
    - Short term radio resource optimisation
Reconfigurable Base Stations and Terminals

- Reconfigurable base stations
  - Base Station Configuration and Reconfiguration to maximise the networks efficiency

- Reconfigurable terminals
Cognition Enablers

Cognition enablers - Especially for environment with flexible spectrum management

⇒ Cognitive Pilot Channel
  • Distributes information on available radio accesses and their spectrum

⇒ Cognitive Control Radio
  • Exchange of Cognitive Control information between terminals

⇒ Spectrum Sensing
Cognitive Pilot Channel (CPC)

- Cognitive Pilot Channel (CPC): a channel providing information for the operations of Cognitive Radio Systems

- Use Cases
  - Start-up scenario
  - Secondary spectrum usage
  - Radio resource optimisation

- Information model:
Out-band and In-band CPC

- **Out-band CPC**
  - RAT 1, e.g. UMTS
  - RAT 2, e.g. LTE
  - RAT 3, e.g. WiMAX
  - RAT 4, e.g. WLAN
  - RAT 5, e.g. GSM

- **In-band CPC**
  - RAT 1, e.g. UMTS
  - RAT 2, e.g. GSM
  - RAT 3, e.g. WiMAX
  - RAT 4, e.g. WLAN
  - RAT 5, e.g. LTE

- Combinations of Out-band CPC and In-band CPC are also possible

Note: In-band CPC can also be deployed in more than one RAT.
CPC configuration on network side
Here: Downlink in-band broadcast CPC
Listen on broadcast CPC on terminal side

- JRRM-T
- RAT
- RAT
- CPC

CPC Start Listen
CPC Info Notification
CPC Stop Listen

CPC DL BC
Alternative procedure: Dedicated CPC Information Request
Combined CPC procedures

- **JRRM-T**
  - Outband CPC e.g. GSM
  - RAT e.g. LTE CPC

- **RAT e.g. LTE CPC**

- **Outband CPC e.g. GSM**

- **JRRM-N**
  - Out-band broadcast CPC
  - In-band on-demand CPC

**Power-on**: Listen to out-band CPC
- CPC Start Listen
- CPC Info Notification
- CPC Stop Listen

Switch to In-band CPC
- CPC Info Request
- CPC Info Notification
- CPC Info Request
- CPC Info Answer

**CPC Info Notification**: CPC Info Request

**CPC Info Request**: CPC Info Answer
Fields of Interest in Standardization

- Regulation
- Autonomic and Cognitive Management in Radio Systems
- System Architecture and Interfaces
- Radio Equipment Architecture and Interfaces
- Specification Techniques for Radio Development
- Radio Equipment Architecture and Interfaces
Standardization activities to support global harmonization

Activities in ETSI
(European Telecommunications Standards Institute):

⇒ E²R II opened the path towards ETSI activities, and E³ continued participating actively

⇒ ETSI Technical Committee on Reconfigurable Radio Systems (TC RRS) has been created in 2008, extension of mandate in Sept. 2009.

⇒ Several reports have been published in 2009, e.g.
  • ETSI TR 102 682 “Functional Architecture (FA) for the Management and Control of Reconfigurable Radio Systems”
  • ETSI TR 102 683 “Cognitive Pilot Channel”
  • ETSI TR 102 838 “RRS Standardisation Issues in the area of SDR and CR – results or RRS in 2009”
IEEE Standards Coordinating Committee 41 (SCC41) on “Dynamic Spectrum Access Networks”:

- IEEE P1900.4
  - E3 project has been very active in the initiation, consolidation and successful finalization of the first P1900.4 version of the draft standard
  - Continuation in the area of
    - detailed interface design (1900.4.1)
    - DSA in White Space Frequency Bands (1900.4a)

- IEEE P1900.6 focuses on the interfaces between sensing and decision making mechanisms in cognitive radios, cognitive radio systems and in dynamic spectrum systems in general
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<th>E3 involvement</th>
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| **Regulation:** | ITU WP 1B on CR  
 |                   | E3 monitors  
 | ITU-R WP5A on CR | E3 contributes  |
| **Autonomic and Cognitive Management:** | ETSI RRS WG3 (CPC)  
 |                   | E3 leads  
 | IEEE SCC41 P1900.6 | E3 contributes  |
| **System Architecture and Interfaces:** | IEEE SCC41 P1900.4  
 |                   | E3 contributes  
 | ETSI RRS WG3 (FA) | E3 leads  |
| **Radio Equipment Architecture and Interfaces:** | ETSI RRS WG2  
 |                   | E3 contributes  
 | SDR-F (Digital RF) | E3 leads  |
| **Specification Techniques:** | OMG, SDR-F, OMA, ACF  
 |                   | E3 contributes  |
Summary and conclusions

- E3 Functional Architecture including functionalities for
  - Self-organizing networks and autonomous entities
  - Reconfiguration of network elements and devices
  - Dynamic Spectrum Management
  - Joint Radio Resource Management
  - Cognition Enablers (CPC, CCR, SS)

- Ongoing related standardization activities (ETSI RRS, IEEE SCC41) to support global harmonization

- E3 project has made fundamental design and development work for introducing cognitive systems into wireless communication infrastructures
Thank you!

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