From Reconfigurability towards Cognition: Resource Management Platform for enhancing Future Systems’ Performance

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Overview

✓ Contribution of E2RI/II in B3G world
✓ Management functionality (materializing the E2RI/II contribution)
✓ Functional architecture for radio resource and spectrum management
  ➢ Temporal
  ➢ Spatial aspects, distribution levels
✓ Analysis of components
  ➢ Context information, Profiles, Policies
  ➢ Optimisation schemes
✓ Advanced spectrum management
✓ Joint Radio Resource Management
✓ Dynamic Network Planning and Management
✓ Migration towards cognition
Overall E2RII contribution in the B3G world

What relevant problem does E2RII solve
- E2R contribution in the B3G world: Easy deployment and coexistence of RATs

What differentiates E2RII solutions
- E2RII solution: each radio network is modeled as a reconfigurable segment
- Reconfigurable segment consists of:
  - Reconfigurable platform
    - Different configurations (potentially RAT, spectrum) on the same hardware platform
  - Management functionality
- Reconfigurable platforms
  - Maintain RAT, change spectrum
    - E.g., legacy system operated in new spectrum
  - Change RAT, maintain spectrum
    - E.g., new system operated in legacy spectrum
  - Change RAT, change spectrum
    - Flexible spectrum management
- Management functionality
  - Management of radio resources in a reconfigurable/cognitive network context
  - Equipment management and control
  - Radio enabler for collaboration of network and terminal management

B3G world: Heterogeneous network infrastructure (Radio Access Technologies – RATs)
- Mobile
- WWAN, WMAN, WLANs
- Short range connectivity
- New air interfaces

Basic B3G concept: Select best available RATs and networks

Sophia Antipolis, France, 09 Feb 07

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E2RII Management functionality

**TRM module**

**NRM module**

- **TRM: Terminal Reconfiguration Management**
  - Management of equipment in a reconfigurable (cognitive) B3G network context
  - Monitoring, discovery, security, profile, negotiation, selection, etc., functionality
  - Design, development, prototype (laptop, Nokia, Motorola devices)

- **NRM: Network Reconfiguration Management**
  - Management of radio resources and spectrum in a reconfigurable (cognitive) B3G network context
  - Based on context, profiles, policies
  - Efficient optimization functionality
  - **E2RII approach: Functional Architecture (FA)**

- **Radio Enabler**
  - Collaboration of terminal and network management
  - Supporting cognition (avoid scanning the frequency band and discovering without assistance)
  - **E2RII approach: Cognitive Pilot Channel (CPC)**
Three loops:
- Inner loop
  - Short term processes
  - User, cell
- Middle loop
  - Mid term process
  - User, cell, regional
- Outer loop
  - Long term process
  - Regional, cell

Each process is involved in one or several loops
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Validation and verification is set up to test the wireless system.

The system is validated using both simulation and measurement in different environments.

The radio system is measured with a test tool:

- Test tool 1: Modulation and demodulation of the signal
- Test tool 2: Measurement of the signal in real-time
- Test tool 3: Analysis of the signal in the frequency domain

The validation results are then compared with the simulation results to ensure the accuracy of the system.

The wireless system is then demonstrated in a real-world scenario:

- Scenario 1: Indoor environment with multiple devices
- Scenario 2: Outdoor environment with high interference

The system performs well in both scenarios, demonstrating its robustness and reliability.

In conclusion, the wireless system is validated and verified through rigorous testing and real-world demonstration, confirming its suitability for diverse environments and applications.

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Context Information from Discovery Procedures

- Estimation of capabilities (capacity and coverage) that can be achieved by alternate configurations of the transceivers of the element
- Approaches based on interference temperature and SNR computations
- Cooperation between the managed element and the users/devices in the service area can be required
- Cognition: Basic discovery + Machine Learning
Profiles

- Monitoring
- Discovery
- Optimization
- Reconfiguration
- Policies

 ✓ Acquisition and maintenance of information (data and knowledge) on managed element, devices, users, applications

 ✓ Managed element:
   - set of wireless transceivers
   - set of RATs that can be used per transceiver
   - sets of carriers, transmission power levels, etc per transceiver / RAT

 ✓ Users:
   - applications that each user can use (e.g., has subscriptions)
   - permissible QoS levels per application, agreed between the user and the NO, and the associated traffic and mobility behaviour of the user;
   - importance (utility) and maximum allowable (or indicative tolerable) cost, associated with each QoS level of each application.
 ✓ Constraints that have to be respected in the handling of contextual situations
   ➢ RATs that are allowed for operation in each transceiver
   ➢ Frequencies and transmission powers that can be used
   ➢ Applications and QoS levels that are allowed to be offered
 ✓ Rules or strategies which should be followed in context handling.
   ➢ Correspondence between configurations and each contextual situation
   ➢ These correspondences can be used as rules, which must be followed, or give suggestions
Optimization Functionality

- **Optimization functionality** is needed in order to obtain Optimal Reconfigurations
- **ASM**: Advanced Spectrum Management
- **JRRM**: Joint Radio Resource Management
- **DNPM**: Dynamic Network Planning and Management
Advanced Spectrum Management - Schemes

- Exploitation of spectrum sharing (secondary usage) between systems operated either by the same or different NOs
  - Auctioning between systems at user-, cell- or NO- levels
    - Anglo-Dutch with split award
    - Rubinstein-Stahl bargaining
    - Evolution of DCA (Dynamic Carrier/Channel Allocation)
  - Cell-by-cell allocation (spectrum allocation, borrowing)

- Flexible spectrum allocation of bands to RATs used by a single NO
  - Multi-user resource (subcarriers, power) allocation management
  - Swarm intelligence: Porting of technique used for self-organization of insect populations to resource optimization space
  - Game theory: Cooperative/non-cooperative schemes for acquiring get resources and maximizing utility functions
The inputs available for JRRM decisions consist in the following.

- The RATs deployed,
- The bandwidth available for each RAT
- The scenarios configuration (i.e. base station maximum transmitted power level, code sequences available in case of WCDMA based RATs, etc.).
- Measurements from RANs (e.g. load levels) and terminals (e.g., received power levels, path loss, Ec/Io, etc.)
- Techno-economical aspects (profiles), and NO policies

The outputs of the JRRM operation include the following parameters.

- A recommendation for a potential update on the RAT selection,
  - For a new session (joint admission control)
  - During a session (vertical handover).
- Allocation of packets to RATs also feasible (joint packet scheduling).
- Dynamic resource allocation = to set allocated resources per user at a time scale with fine granularity (e.g. at frame level).

Fuzzy-neural JRRM framework
Dynamic Network Planning and Management

- Dynamic network planning and flexible network management (DNPM) is a suite of software components
- Focus on the management of radio resources and spectrum of a reconfigurable network
- The output is a new configuration at the network segment level
  - Selection of RATs per transceiver
  - Selection of spectrum per RAT and transceiver
  - Assignment of demand to RATs, spectrum
  - QoS (utility) maximisation subject to capacity/coverage constraints

- Distributed, utility-based greedy algorithm (RDQ)
- RDQ: Distributed RAT selection, Demand partitioning, and QoS levels assignment implemented in phases

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Guidance is needed in a context that includes flexible spectrum management, as well as cognition and autonomicity.

Information exchange (high level)
- Terminal provides context (position, RAT/spectrum aspects in the area)
- Network responds with policies to be followed by the terminal

Procedures
- Sensing
- Cooperative Sensing (multiple terminals)
- Network Supported → the Cognitive Pilot Channel
From reconfigurability to cognition

- Reconfigurable networks
  - Reconfigurable platforms
  - Management of reconfigurability
  - Basic cognitive network technologies integrated

- Cognitive networks
  - Exploit reconfigurable platforms
  - Evolved management functionality is required
  - Cognition is a dynamic process, affected by time and space variations
  - Information from previous interactions with the environment is retained
  - Proactively response to environmental stimuli is enabled
  - Learning functionality required, with a feedback loop operation, e.g., the Observe-Analyse-Plan-Act (OPA) loop
Moving towards cognition

✓ Goals: what should be optimized
   - number of users and devices that should be served
   - QoS levels, at which the requested applications are provided

✓ The loop is guided by a set of **goals**, which take **observations** into account when **planning actions**
Conclusions

✓ Contribution of E2RI/II in B3G world
  ➢ Overall view
  ➢ Management functionality (materializing the E2RI/II contribution)
  ➢ Functional architecture for radio resource and spectrum management

✓ More information: visit http://e2r2.motlabs.com/
  ➢ Further supporting information
  ➢ Dissemination
  ➢ Results

✓ Future plans
  ➢ Introduce cognitive systems in the B3G world
Secondary spectrum usage between systems is motivated by the fact that spectrum measurement campaigns have shown that spectrum is not scarce, but is mostly under- or not appropriately used by the current RATs.

Substantial temporal traffic patterns variations have been observed for cellular voice services as well as for TV broadcast systems.

These measurements have established the existence of “white spaces”, even during peak times, when looking into smaller temporal resolutions (milliseconds to minutes).

Spectrum occupancy measurements of all bands between 30 MHz to 3000 MHz showed occupancy varying from less than 1% to 77%.

The overall average usage of the spectrum within the measurement range amounted to 13% during a peak use period.
Joint Radio Resource Management - Rationale

 ✓ Interworking between different RATs leads to better overall performance than the accumulated performances of the stand-alone systems

 ✓ Introduction of radio resource management algorithms that take into account the potential QoS levels offered by the available RATs

 ✓ Various solutions to the JRRM problem
   ➢ Determined by operational scenario, service mix conditions, QoS constraints, etc

 ✓ Fuzzy-neural JRRM framework

 ✓ JRRM operation can interwork with ASM/DNPM mechanisms
Radio Enabler – The Cognitive Pilot
Channel concept

✓ Enabling – radio access in heterogeneous radio access technology environments in single and multi operators scenarios

✓ Issue: Out-band or In-band or both
  - “Out-band” means physical channels outside the component Radio Access Technologies
  - “In-band” refers to logical channel within the technologies of the heterogeneous radio environment

✓ Cognition support through both downlink and uplink capabilities