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Cognitive multi-mode and multi-standard base stations: architecture and system analysis

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A Consortium
Selex Communications S.p.A. (A Finmeccanica Company) – Telespazio S.p.A. (A Finmeccanica/Thales Company)
University of Rome "Tor Vergata" – University of "L'Aquila" – Università of Rome "RomaTre"

Outlines

- Partners' description
- Introduction
- Flexible wireless architecture
    - Multi-mode base station
- Scenario and system architecture
- Planning and deployment of Multi-mode radio access network
- Cooperation among Technologies
- Results
- Conclusions

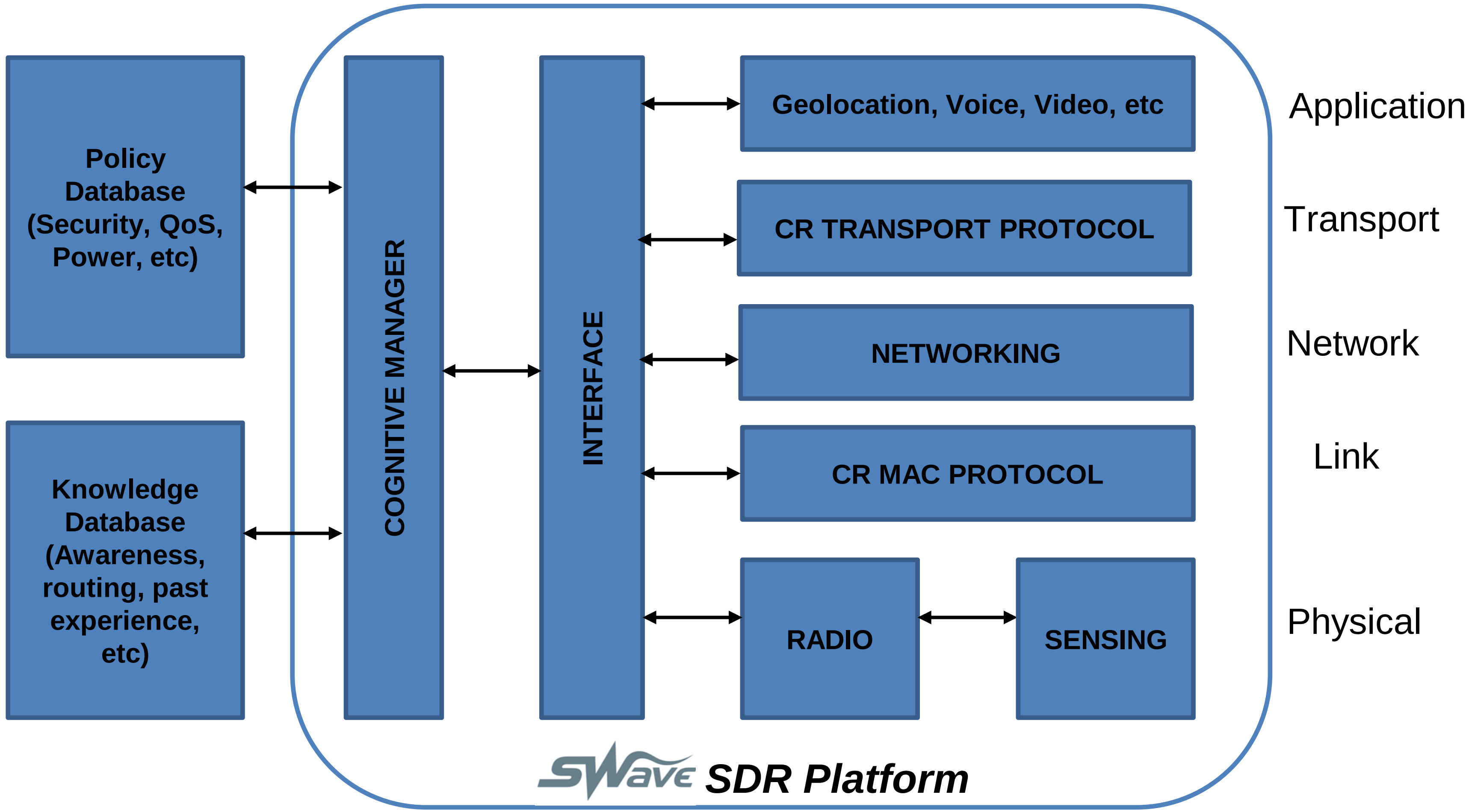
SELEX Elsag

SELEX ELSAG
Secure Networking Solutions
A Finmeccanica Company

Created on 1 June 2011 by the merger of SELEX Communications with Elsag Datamat, an operation also involving SELEX Service Management and Seicos, SELEX Elsag is the Finmeccanica Group company specialised in the design and development of hi-tech systems, products, solutions and services for the following business areas:

Military BU - SELEX Elsag

Possible update of SDR Platforms to COGNITIVE architectures



SELEX Elsag SDR SWave Platforms and Waveform

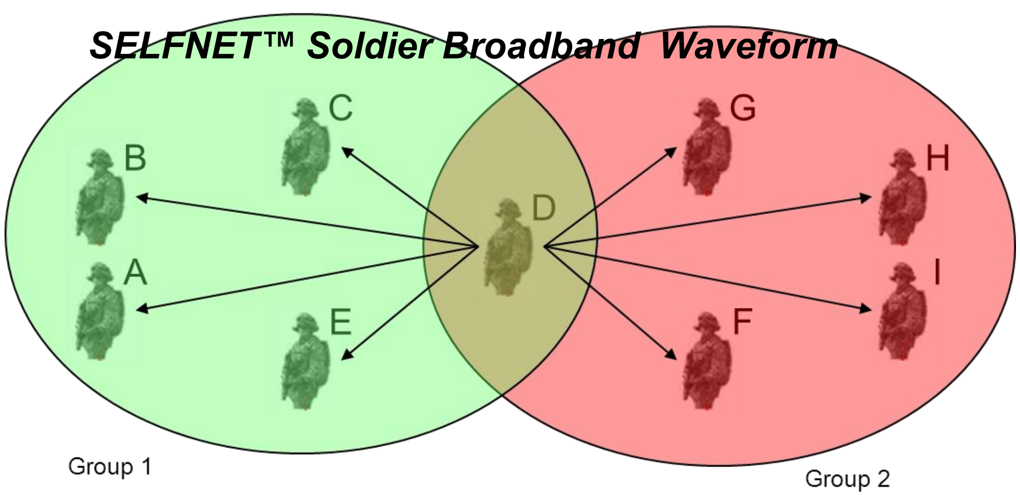
SWave HANDHELD

SWave *Vehicular Mono-Channel*

WIDEBAND

QoS

MANET



MULTIHOP

VOICE/DATA SERVICES

R. Pucci – SDR'12 WinnComm

RadioLabs

standing for

"Consorzio Università Industria – Laboratori di Radiocomunicazioni"

Research Consortium

(home page: http://www.radiolabs.it)

- *Consortium founded in 2001*
- *Headquarters located in Rome, Italy.*

Introduction

- Mobile communications standards developed worldwide to operate within 800 MHz up to few GHz
- Each technology optimized to provide a specific set of services, according to technical and economic aspects
- Waveforms of different standard are characterized by different parameters in terms of transmitted power, occupied bandwidth per channel and Quality of Service (QoS)
- Two solutions for supporting several technologies:
  - Software Defined Radio (SDR) → not diffused
  - Multi-mode technology optimized for the device (e.g. terminal) → preferred
- Multi-mode → **Flexible wireless network architecture**

Multi-mode Base Station

- The possibility of changing the communication technology involves:
  - Redistribution of users and services among technologies in the same area
  - Introduction of flexible management procedures of power and spectrum resources in accordance to the offered traffic
- A flexible wireless network architecture can be based on multi-mode BSs able to transmit/receive signals in accordance to several wireless access standards (e.g. 2G, 3G, 4G-LTE and even Wi-Fi). Research challenges on:
  - algorithms and techniques for self-organization/configuration, self-healing and self-optimization for the best use of radio resources available in different frequency bands (i.e. from 900 MHz up to 3 GHz)
  - collaborative functionalities, mainly oriented to the (fair) spectrum sharing among the different operators

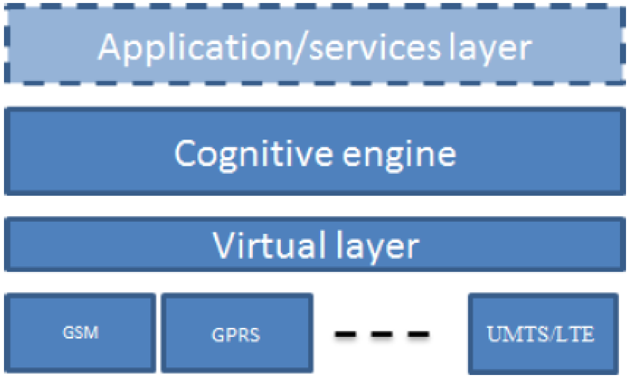
Multi-mode Base Station (2)

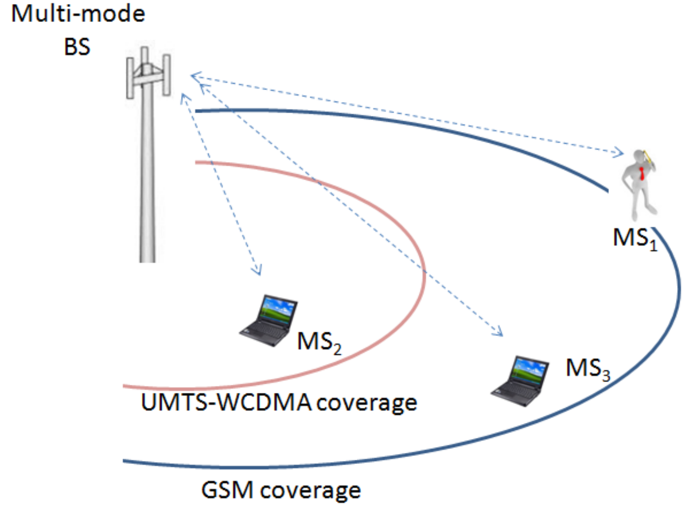
- Flexible wireless architecture
  - Each operator has its own infrastructure and can share spectrum resources with other operators
  - The access network owned by each operator includes **multi-mode BSs**
- Multi-mode BS:
  - Communicates with terminals in accordance to one or more radio standards such as GSM/GPRS, EDGE and UMTS including LTE
  - Has assigned a bandwidth *B*
  - Can assign part of the band *B* to a certain technology according to e.g.:
    - Offered traffic to the network
    - Required services
    - Priority of users
    - Energy issues
  - Example of service division among technologies (Table)

Technology	Coverage	Supported bit rate	Service examples
GSM	High	Low	Voice, SMS
GPRS/EDGE	Medium/ high	Low/ medium	Email, browsing
UMTS-WCDMA	Medium	Medium	Gaming, content download
UMTS-HSPA	Low/ medium	High	Streaming
UMTS-LTE	Low/ medium	High with lower delay	Conference

Architecture with Multi-mode BS

- Multi-mode BS has multiple standards (e.g. GSM, GPRS, EDGE, UMTS-WCDMA, UMTS-HSPA and UMTS-LTE)
- Virtualization layer for PHY abstraction
- Cognitive and management layer handles the access to the radio resources taking into account for:
  - The requests of users, QoS requirements
  - Information on user position, their channel quality, the power required for transmission(s)
  - The interference situation and the congestion status of the cell





Architecture with Multi-mode BS (2)

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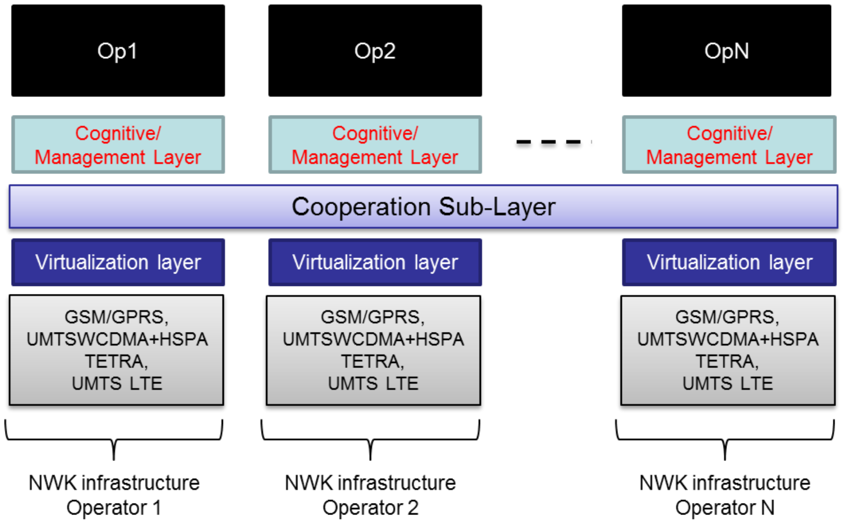
- Flexible Radio Access Network (RAN)
- Operators appear like "applications" running over the cognitive/management layer
- Each operator owns one physical network infrastructure and exerts full control/management over it
- The physical network is completely virtualized
- Cognitive/management layer implements algorithms for the (self) optimization of radio resource utilization
- Operators contend the access to transmission resources i.e. the channels



Planning and deployment of Multi-mode RAN

RadioLabs

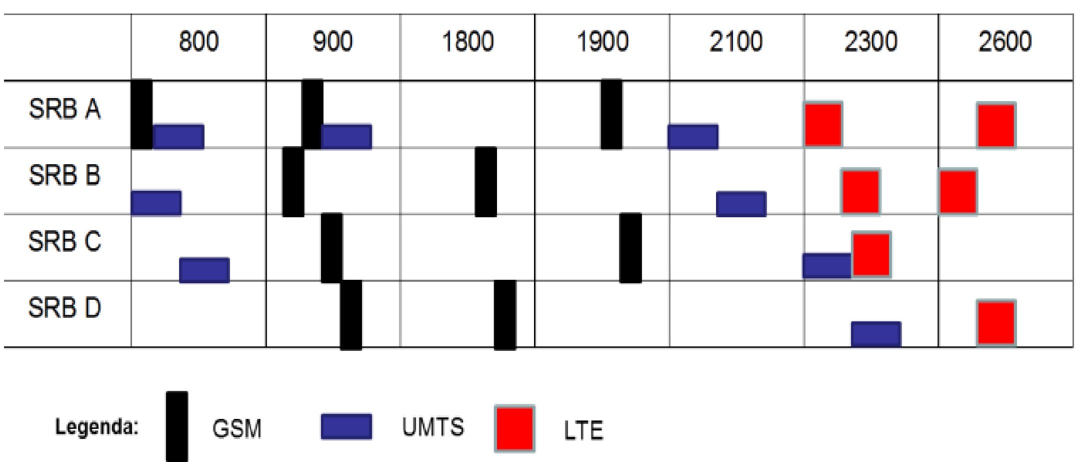
- **Step 1: Network design and deployment**
- Initial positioning of BSs in the area → Determining the distance among BSs
  - Selection of one technology according to expected offered traffic and type of area (e.g. urban, sub-urban or rural)
  - After initial deployment, network can gradually evolve to accommodate more traffic by adding multi-mode BSs so reducing the inter-BSs distance
  - Network growing can continue until all the service area can be served by a single high capacity technology such as LTE (or a newer one).
- Then, one or more BSs can adaptively change technology: BSs can increase or decrease their coverage → use of self-organizing algorithms

- **Step 2: Network entry**
- BSs transmit signaling channels in accordance to the reference radio technologies used for initial planning → Network entry is carried out using the procedures specific for these technologies

Planning and deployment of Multi-mode RAN (2)

- **Step 3: Classification and description of communication services**
- Service classification respect to supporting technology:
  - Voice: supported by GSM+GPRS, WCDMA, LTE
  - Data – Category 1 (up to 200 kb/s with different QoS requirements): supported by GSM+GPRS, EDGE, UMTS, LTE
  - Data – Category 2 (from 200 kb/s up to 500 kb/s with different QoS requirements): supported by WCDMA, LTE
  - Data – Category 3 (more than 500 kb/s with different QoS requirements): well supported only by LTE
- Service classification respect to the technology coverage extension:
  - Voice: services offered by GSM+GPRS up to 5 km (to be conservative); WCDMA: up to 1 km; LTE: up to 500 m
  - Data Cat. 1: services offered by GSM+GPRS, EDGE up to 4 km; WCDMA: up to 1 km; LTE: up to 300 m
- Classification used for the smart assignment of radio technology

- **Step 4: Frequency planning and band allocation**
- Visual representation of radio resource allocation in a multi-mode network**:** radio resource optimization



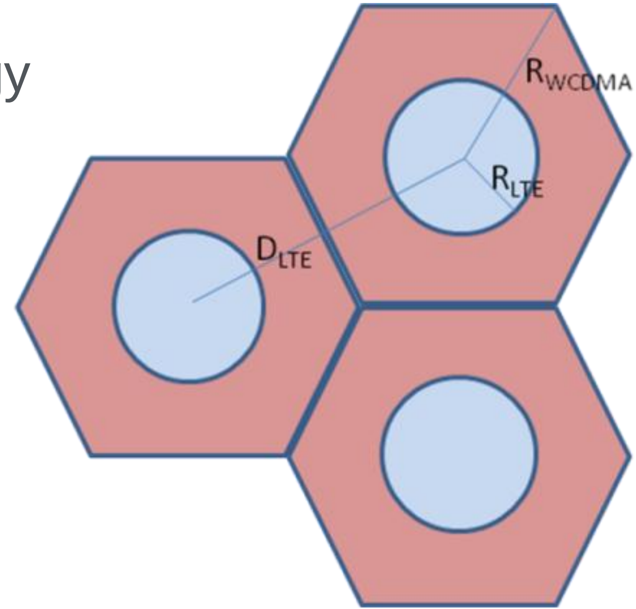
Planning and deployment of Multi-mode RAN (3)

- **Step 5: Request for resources and admission control**
- Basic idea: user should be served using “the best” technology compatible with the required service and QoS requirements and guaranteeing the optimal usage of spectrum and transmission resources
    1. Terminal try to access to the network through the initial dimensioning technology (e.g. WCDMA)
    2. Multi-mode BS measures a favorable channel condition for the terminal enabling the user to be served using a more efficient technology (e.g. LTE)
    3. Multi-mode BS denies the access request and instructs the terminal to move on LTE
    4. Other users can directly connect to LTE if they are inside its coverage area
    5. When the LTE carrier becomes underutilized i.e. the number of user served by LTE is small, LTE traffic can be re-directed to WCDMA and LTE carrier turned off

- ***Issues***:
- When a new carrier is turned on it is necessary to consider co-channel interference and ACI
- Admission control (AC) procedure should avoid overloading situations
    - One radio technology used to off-load the initial technology (hotspot handover)

Cooperation among Technologies

- Telecommunication operators are able to share their spectral resources (virtualization layer)
- Overall bandwidth for UMTS-WCDMA system (f = 2 GHz), N_u = 9 bandwidth of 5 MHz assigned to 4 telco operators
- Operators have co-located BS according to an optimization criterion
- A second technology could be deployed i.e. some WCDMA carriers could be turned off and UMTS-LTE carriers could be turned on
- Operators can select the proper technology based on required service and coverage criteria



Cooperation among Technologies (2)

RadioLabs

- WCDMA users can moved to LTE to off-load the system
  - WCDMA user, N_{WCDMA}
  - η_{UL} load factor, W = 3.84 Mchip/s,
  - i = other_cell_interf./own_cell_interf.,
  - R_b user bit rate, v user activity factor, $(E_b/N_0)_t$ service target

$$N_{WCDMA} = \frac{\eta_{UL}}{1+i} \cdot \left(1 + \frac{W}{R_b \cdot v \cdot \left(E_b/N_0 \right)_t} \right)$$

- Number of user off loading WCDMA and moved to LTE: $\gamma \cdot N_{WCDMA}$ per cell
  - γ: off loading factor

$$\gamma = \frac{{R_{LTE}}^2}{{R_{WCDMA}}^2}$$

- The off loaded users can be replaced a fraction γ
- A fraction of replacing users falls in the LTE coverage area and then it could be moved again: $\gamma^2 N_{WCDMA}$
- $N_{off} \le N_{LTE}$: number of off loaded users after L iterations, with

$$N_{off} = N_{WCDMA} \sum_{l=0}^{L} \gamma^l = N_{WCDMA} \cdot \gamma \cdot \frac{1-\gamma^L}{1-\gamma}$$

$$N_{LTE} = \frac{N_{system\_carrier}}{N_{user\_carrier}} \cdot \frac{R_{b-LTE}}{R_b}$$

$$R_{b-LTE} = \left(3 \cdot g_{64QAM} + 2 \cdot g_{16QAM} + 1 \cdot g_{QPSK}\right) \cdot \frac{N_{sym} \cdot 2bit}{1ms}$$

Results

- For LTE reuse distance = 1, evaluation of the other cell interference → maximum noise raise r → maximum γ with reuse 1

$$\gamma_M \equiv \gamma = 4 \cdot \left(1 + \left({}^{E_b}/_{N_0}\right)_t \cdot \frac{r}{r-1}\right)^{\delta/2}$$

- We assume $(E_b/N_0)_t$ = 7 dB for QPSK, $(E_b/N_0)_t$ = 13 dB for 16QAM, $(E_b/N_0)_t$ = 19 dB for 64QAM and r=2 dB
- Results for γ regions are reported in Table,with δ propagation exponent

	δ=3	**δ=3.5**	**δ=4**
$\gamma_{QPSK} \equiv \gamma$	0.5959	0.7335	0.8520
γ_{16QAM}	0.2606	0.3701	0.4778
γ_{64QAM}	0.1080	0.1770	0.2546

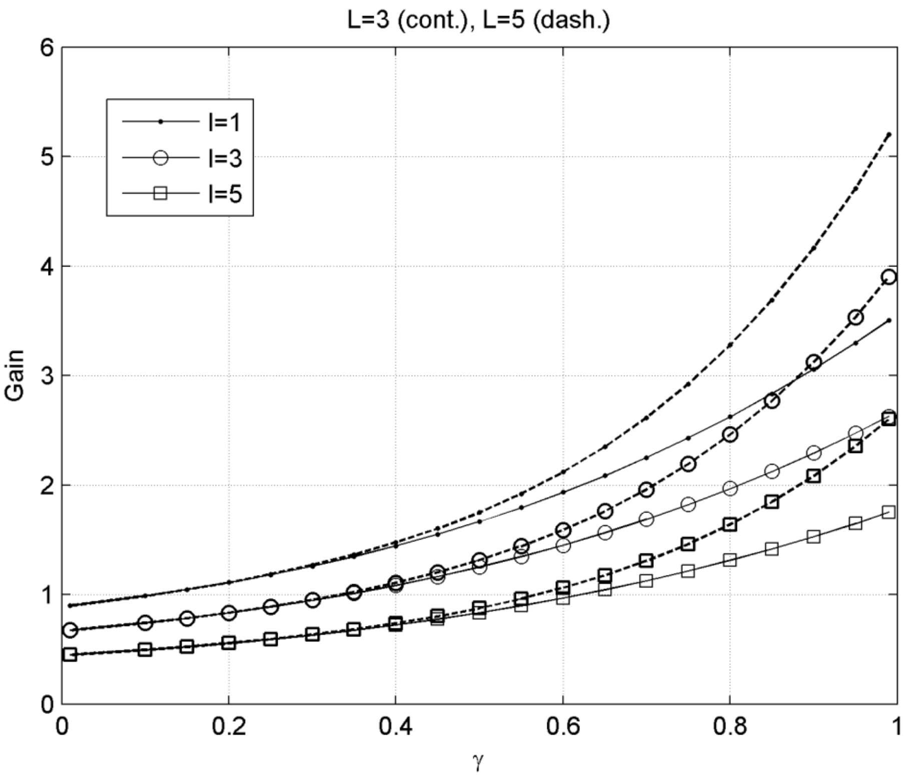
Results (2)

- Improvement due to smart technology selection evaluated respect to the case which the operators work in their assigned bandwidth separately
  - The **gain of technology selection**
  - *l:* number of 5 MHz bandwidth assigned to LTE technology.

$$G_{TS} = \left(1 - \frac{l}{N_u}\right) \cdot \left(1 + \gamma \cdot \frac{1-\gamma^L}{1-\gamma}\right)$$

- G_{TS} vs γ (figure)
- *L* and *l* parameters

→When $G_{TS} \geq 1$, it is convenient to adopt this strategy (for $\gamma \leq \gamma_M$, $N_{off} > N_{LTE}$)



Conclusions

- The adoption of multi-mode BS offers an additional degree of freedom for efficient usage of the radio resources
  - Radio access systems providing spot-like coverage has been proposed in order to off-load primary mobile radio systems
- The proposed system architecture highlights a virtualization layer for a full cooperative access network.
- Planning procedure has been described to allow the deployment of Multi-mode access network
- Selection technology algorithm has been highlighted and its performance have been evaluated