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WETW 2035

Outline

- **Wireless networks today**
- Internet evolution
- **Wireless networks tomorrow: cognitive radio**
- **Cognitive radio research**
  - Research areas
  - Experimentally-driven research
- **Belgian research efforts on cognitive radio**
- **Conclusions**

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The importance of experimentally-driven research on cognitive radio

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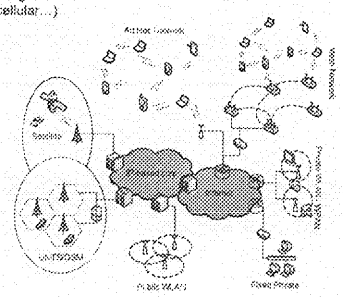
imec UNIVERSITEIT GENT Universiteit Antwerpen

Internet evolution: multitude of networks

- 4G communication networks
  - Evolution towards a "network of networks", integrating different technologies (WLAN, UMTS, Ad Hoc, cellular…)
- Characteristics:
  - IP-based
  - Broadband
  - Wireless access
  - Support of mobility
  - Heterogeneity
  - …



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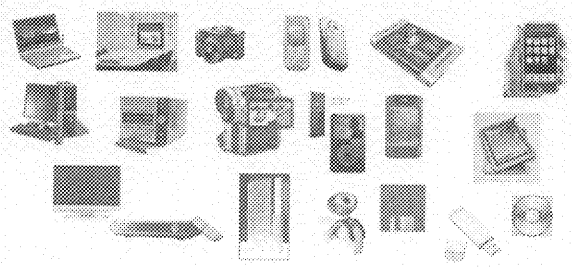
Internet evolution: multitude of end devices (1)

- Personal devices



Wireless networks today

- A multitude of wireless technologies & standards
  - building on proprietary or standardized radio technologies

3GPP GSM lte UMTS WiMAX RFid wimax WiFi Bluetooth ZigBee UWB

- Tuned for a specific application
- Many non-interoperable solutions
  - different architectures
  - different protocols
- Assumption of homogeneous nodes
  - same protocol stack on all nodes within network
- No cooperation between networks

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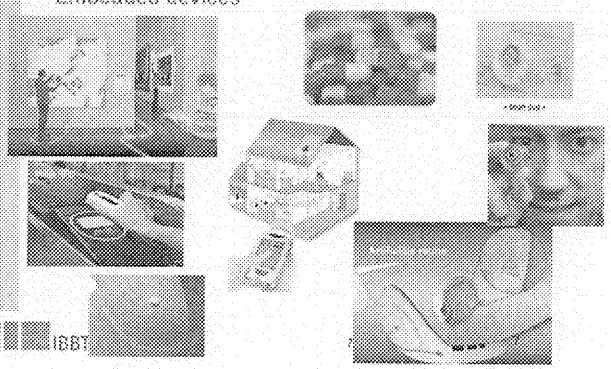
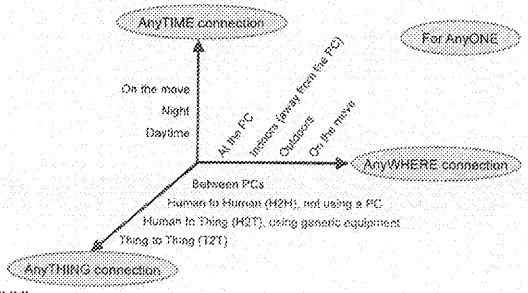
Internet evolution: multitude of end devices (2)

- Embedded devices



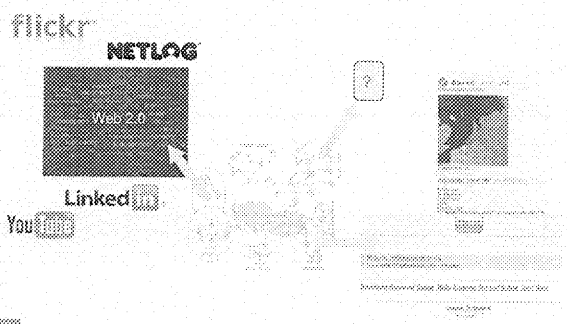
Cognitive radio and 4A vision

- The 4A vision (ITU)
  - AnyTIME, AnyWHERE connectivity for Anyone



Source: ITU Internet Reports 2005: The Internet of Things

Internet evolution: a multitude of services



Cognitive radio and 4A vision

- AnyTIME connection
  - enough spectrum, no matter when (daytime, night, on the move...)
- AnyWHERE connection
  - enough spectrum, no matter where (home, office, indoor, outdoor, at events, on the move...)
- For AnyONE
  - enough spectrum, no matter who (young, old, skilled, non-skilled...)
- AnyTHING connection
  - enough spectrum, no matter which device (from powerful PCs/laptops up to small embedded devices with very limited capabilities).

Internet evolution: a multitude of co-located wireless devices

- Observation
  - Growing importance of mobile & wireless networks
    - Continuous evolution of wireless technologies
    - Ever increasing number/density of wireless devices
    - emergence of wireless sensor networks ("Internet of things")
  - Increasing heterogeneity of the Internet
    - Heterogeneous network technologies
      - wired & wireless networks
      - licensed & unlicensed technologies
      - underutilization of licensed spectrum, scarce unlicensed spectrum
    - Heterogeneous devices
      - network interfaces, memory/processing capacity, power supply, flexibility...
    - Heterogeneous services
  - Dynamics of mobile and wireless environment
    - (un)controlled interference, fading, (dis)appearing of devices...
- Need for more advanced communication paradigms supporting coexistence of heterogeneous wireless technologies

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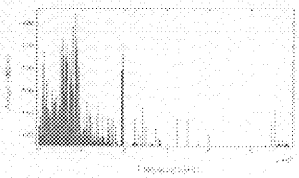
Cognitive radio = spectrum sharing

- Vertical spectrum sharing
  - **primary users** have exclusive spectrum usage rights in a certain band
  - **secondary users** either lease or just autonomously use the spectrum without creating harmful interference to the primaries



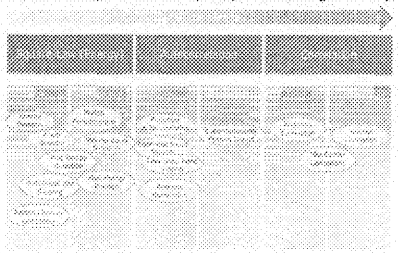
- Horizontal spectrum sharing
  - systems/users having equal spectrum usage rights

Cognitive radio = more flexibility (1)

- Radio flexibility (4-tier concept of SDR Forum)
  - **Hardware Radios**
    - no flexibility, fixed functionality
  - **Software Controlled Radios**
    - Fixed signal path
    - SW interface allows to configure limited number of parameters (current commercial radios)
  - **Software Defined Radios**
    - SW reconfigurable signal path (current SoA flexible radios)
  - **Ideal Software Radios**
    - more functionality of signal path in digital domain
  - **Ultimate Software Radios**
    - blue sky vision: full programmability with analog/digital conversion at antenna

Cognitive radio research areas (1)

- Sensing the wireless environment
  - Identification of spectral opportunities
  - Methods
    - detection performed in time or frequency domain
    - different level of knowledge (energy versus feature detection)
    - different computational complexity and sensing accuracy



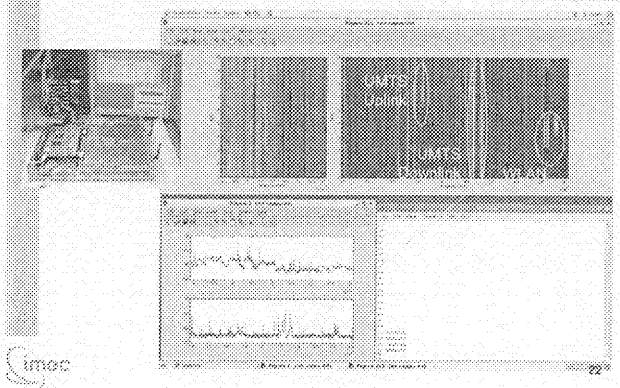
Cognitive radio = more flexibility (2)

- Spectrum access flexibility
  - **No flexibility or fixed access**
    - the frequency allocation scheme is fixed at a given time and location by regulatory bodies
  - **Opportunistic spectrum access**
    - secondary users can actively search for unused spectrum in licensed bands and communicate using these white holes. There is no feedback between primary and secondary users.
  - **Dynamic spectrum access**
    - terminals and technologies can negotiate the use of wireless spectrum locally for a certain time window at run-time. Dynamic spectrum access requires cooperation and negotiation between users.

Cognitive radio research areas (2)

- (Re)configuration of wireless transmission parameters
- Level of collaboration
  - **Level of information sharing**
    - local versus distributed sensing
  - **Local versus global objective span**
    - local versus collective decisions
    - cross-layer, cross-node, cross-network optimization
      → cognitive networking
  - **Optimization objective**
    - minimal interference
    - maximal throughput
    - minimal EM pollution
    - maximal QoS guarantees
    - ...

IMEC low power sensing solution



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Cognitive radio research

- Experimentally-driven research: why?
  - **Dynamic nature of wireless environment**
    - uncontrolled interference
    - complex wireless channels (mobility, fading ...)
    - (dis)appearing wireless devices
  - **Theoretical studies or network simulations are often unreliable**
    - they build on simplified and inaccurate channel models
    - They do not take into account HW limitations
  - **Current experiments are limited**
    - experimental platforms and measurements today are mainly based on laboratory equipment, such as vector spectrum analyzers with high sensitivity
      very low-cost narrowband, limited sensitivity off-the-shelf demonstrators
    - only small scale experiments
    - sensing implementations focused on vertical spectrum sharing (detection of TV signals)

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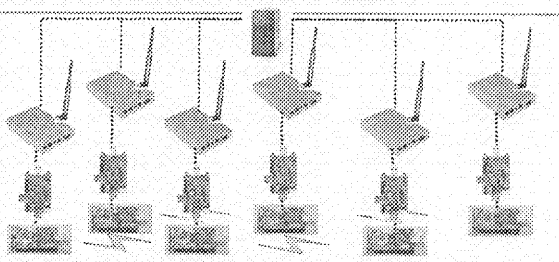
IBBT Wireless Lab - architecture



- 200 nodes (802.11 and 802.15.4) spread over 3 floors of our office building
- COMPLETE remote management of sensor node, environment emulator and embedded pc through web interface
- Web-based, mysql configurable data analysis toolbox
- ACTIVE testbed: Emulation (e.g. replay) of sensor measurements, battery emulation, event emulation, audio injection/extraction, ...

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Cognitive radio research

- Experimentally-driven research: how?
  - Deployment of large-scale **open testbed facilities** in realistic wireless environments in view experimental exploration & validation of cognitive radio research
  - Creation of **flexible experimental platforms** enabling various cognitive radio usage scenarios
    - horizontal and vertical spectrum sharing
    - licensed and unlicensed bands
    - heterogeneous wireless technologies
  - Development of **benchmarking methods**
    - enabling experiments under *controlled and reproducible test conditions*
    - offering *automated procedures* for experiments and *methodologies* for performance evaluation
    - allowing a *fair comparison* between different cognitive radio & cognitive networking concepts or between subsequent developments of diverse approaches
  - Involvement of relevant **stakeholders**
    - Academia
    - industry: equipment manufacturers, network operators, vendors...
    - regulatory bodies
    - standardization bodies

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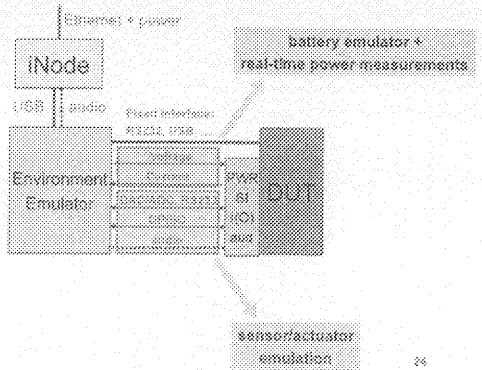
IBBT Wireless Lab: Environment Emulator



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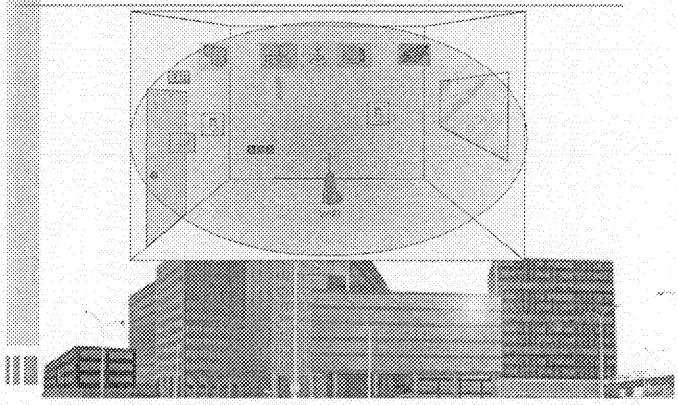
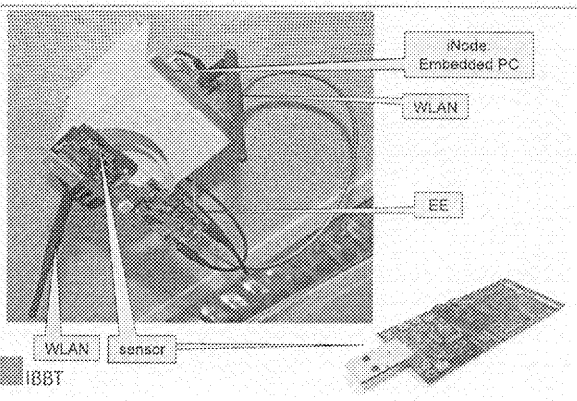
Use case: Wireless Building Automation



iLab.t : Wireless Lab Hardware



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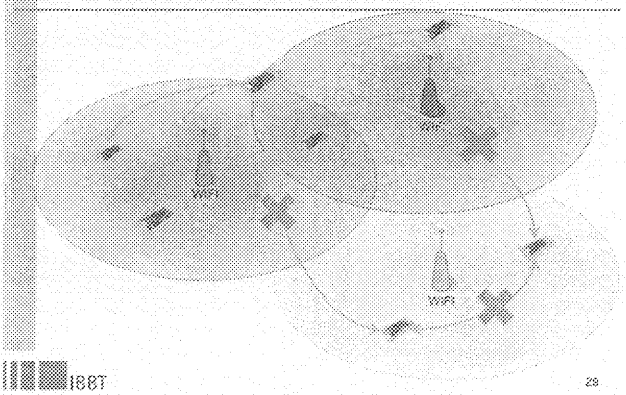
Deploying a sensor network



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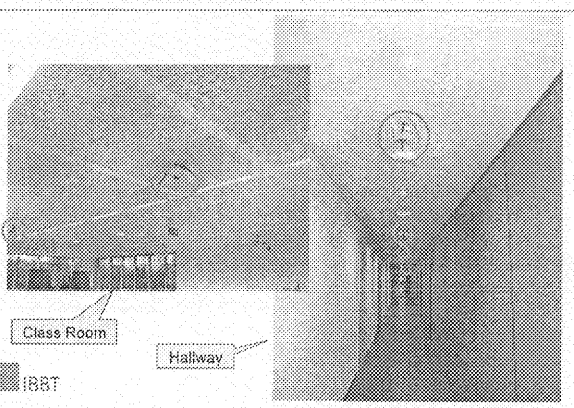
WiLab deployment @ IBBT building



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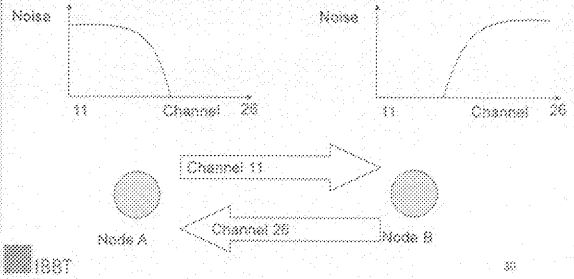
Distributed multi-channel protocol

- Concept
  - autonomous adaptation of receive channel to the dynamic wireless environment
  - facilitation of channel selection by the sensing agent



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IBBT iLab.t – Wireless Lab

- Feature set
  - # nodes, 200 fixed locations, 3 floors @ Zuiderpoort
  - Every node is generic and is equipped with
    - 2 USB, RS232, VGA interfaces
    - 1 or 2 sensor nodes IEEE802.15.4 (+ embedded sensors: Temperature, Light, Humidity)
    - 2 WiFi IEEE 802.11 radios (a/b/g)
    - Extendable: Bluetooth, Software Defined Radio,
  - Every node is powered via PoE and can be disabled
  - Environment emulator (EE)
    - EE can emulate battery voltage of the sensor nodes and can measure the consumed electrical power real time
    - EE can emulate environmental variables like switches, monitored data
    - EE can log the events of the sensor nodes
  - Sensor nodes can measure and react on real and emulated environmental variables
  - Development environment
    - TinyOS (sensor nodes)
    - Click (iNodes)
  - Remote access

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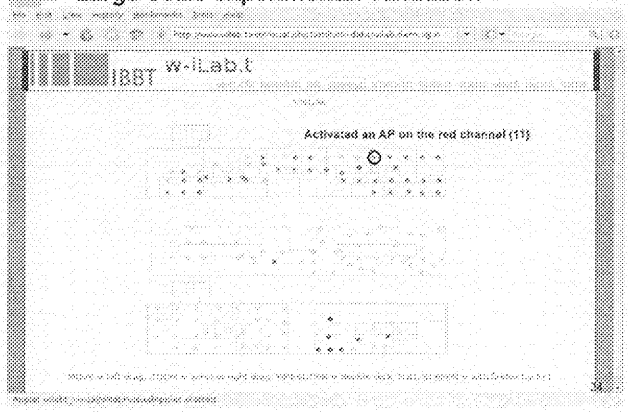
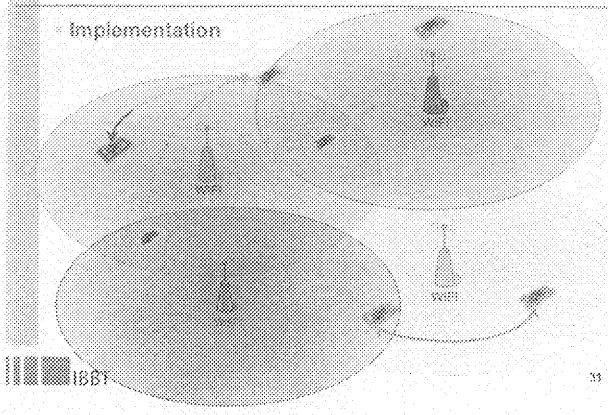
Large-scale experimental validation



Distributed multi-channel protocol

- Implementation



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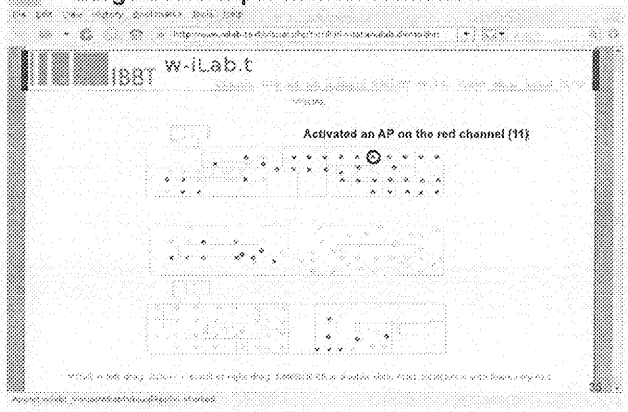
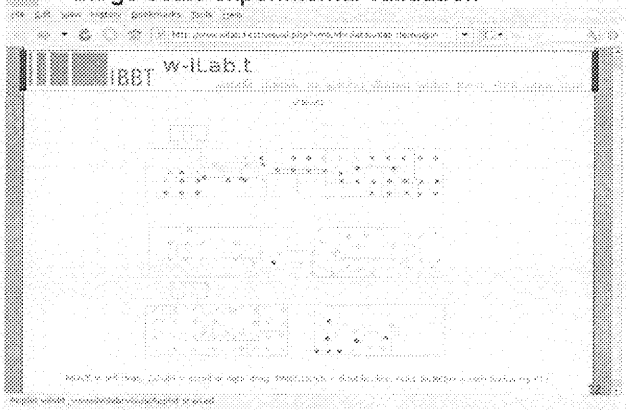


Large-scale experimental validation



Belgian CR experimental facilities

- Heterogeneous ISM test environment @ IBBT
  - Technologies
    - commercial radios:
      - IEEE 802.11 (400)
      - IEEE 802.15.4 (> 200)
      - 802.15.1 (200)
    - open USRP software radios (10)
    - IMEC sensing platform (10)
      - Spectral range: from 1 MHz to 6 GHz
      - Bandwidth: 1 MHz to 40 MHz
  - Benchmarking framework
    - automated experimentation, performances analysis and comparison of cognitive radio & cognitive networking solutions

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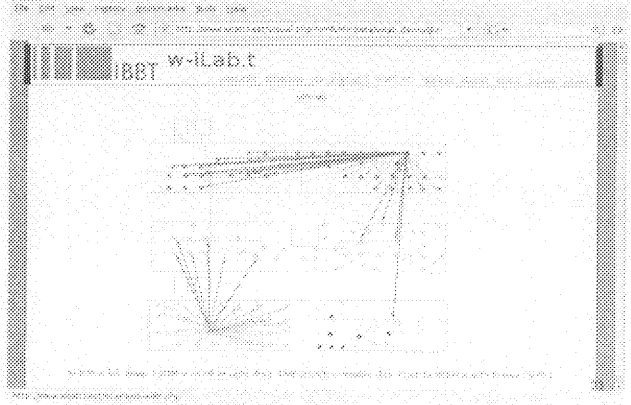
Large-scale experimental validation



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Questions ?

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Conclusions

- **A multitude of heterogeneous**
  - wireless network technologies
  - end devices
  - services
- **Need for new communication paradigms for coping with coexistence**
- **Future =**
  - Cognitive Radio
  - Experimentally-driven research
  - Large-scale open testbed facilities and flexible experimental platforms
- **Deployment of IBBT/IMEC large-scale CR testbed**

Acknowledgement

- IBBT ISBO project NG WiNeTs
  - Next Generation Wireless Networks and Terminals
  - Partners: IMEC, UGent-IBCN, UA-PATS, VUB-SMIT
  - Start: 1 January 2009
- First Workshop
  - Theme: Cognitive Networks: Interference Sensibility
    - Monitoring, avoiding, minimizing and accounting interference
  - Date: Thursday 21 January 2010
  - Location: IBBT, Ghent, Belgium

End-to-End Efficiency

- Project Overview
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End-to-End Efficiency (E^3)

Welcome to the End-to-End Efficiency (E^3) website! E^3 is an Integrated Project (IP) of the 7th Framework Programme of the European Commission, addressing the core of the strategic objective "The Network of the Future". E^3 has started on 01.01.08 and has a duration of 2 years.

E^3Website: First information on the E^3 project starting on 01.01.08.

News

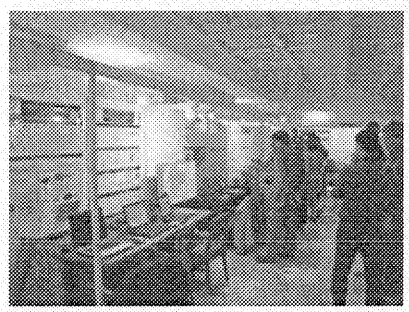
15.-17.12 2009:
E3 members will participate in ETSI RRS meeting, 15-17.12.09, in Mainz, Germany

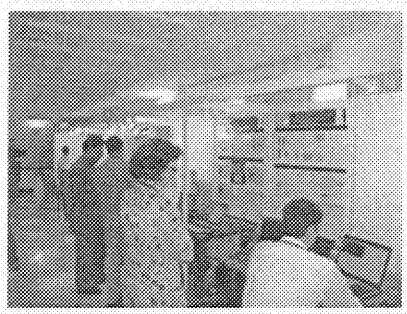
2009-12-07

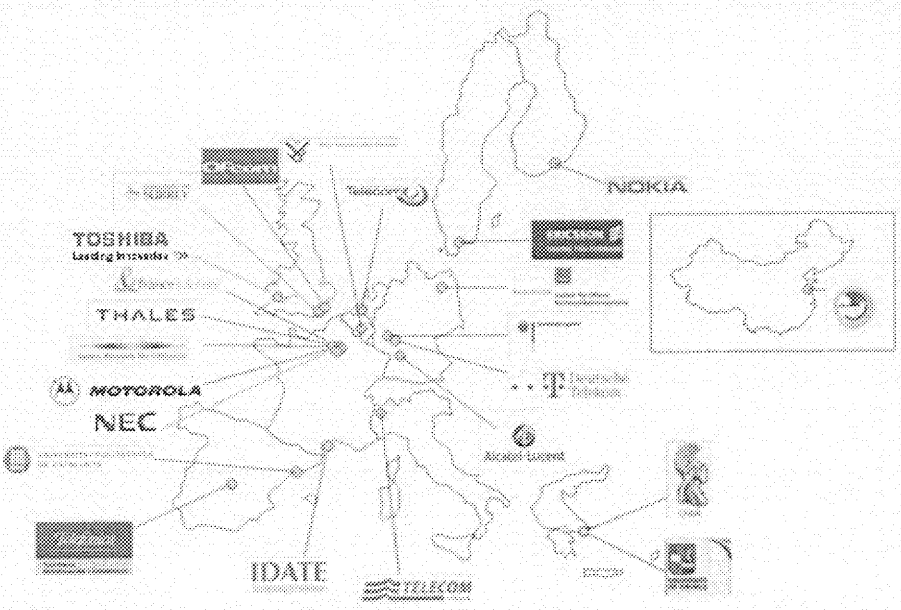
11.12 2009:
Business Model Workshop, 11.12.2009, in Brussels, Belgium has been organised by E3. E3 members will actively participate in the Workshop.

2009-12-07

More...







Visit the different sections of E^3website to learn more about this research project: Project Overview, Approach, Key Challenges, Impact, Workpackages, Schedule, Partners.... The Dissemination section will list the conferences contributions and journals papers, presentations made at concertation and cluster meetings, white papers, standardisation contributions, regulatory contributions, interviews and flyers. The executive summary of all the E^3 Deliverables will be downloadable. Public deliverables will also be accessible online. Information on the training activities, the tutorial, the project glossary will also be available on-line.

Do not hesitate to contact and meet E^3 partners for more information on this project!

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