Needs, research and development on software defined cognitive radio technology

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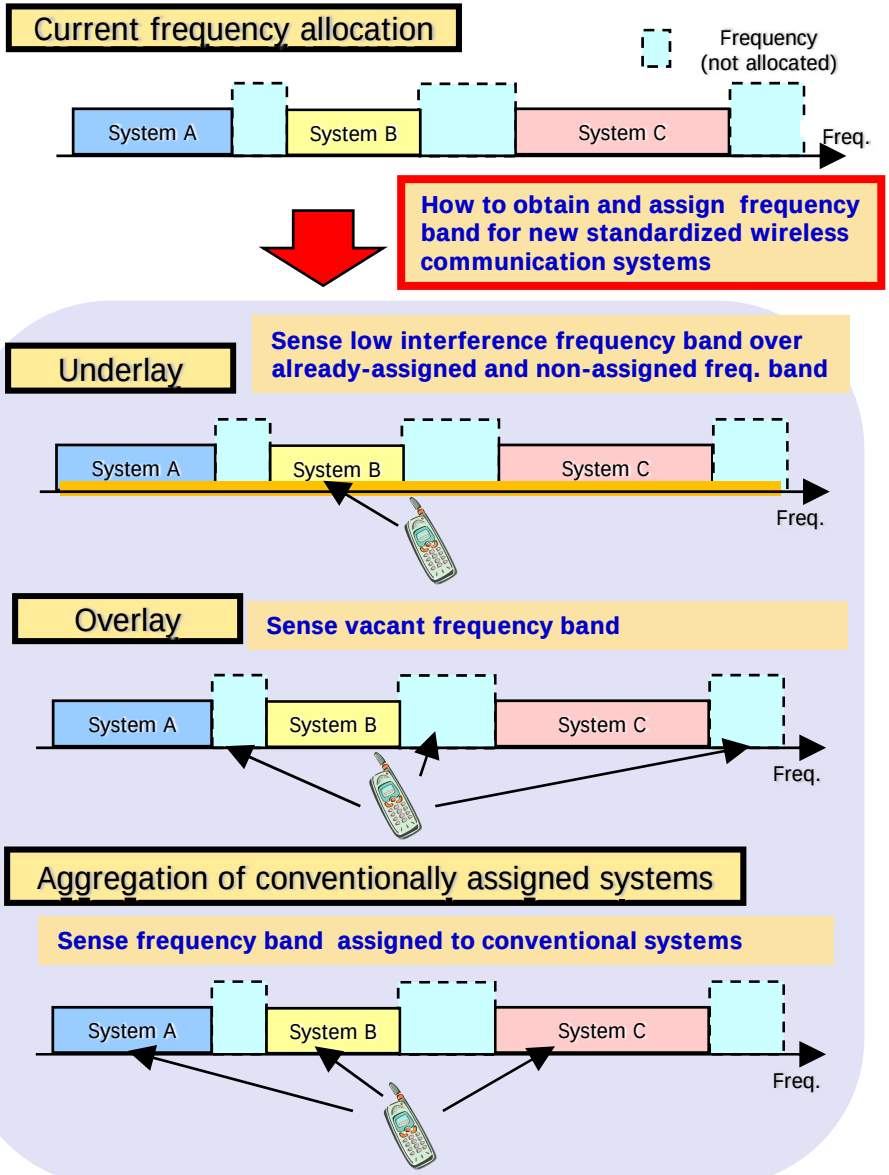
Needs for cognitive radio

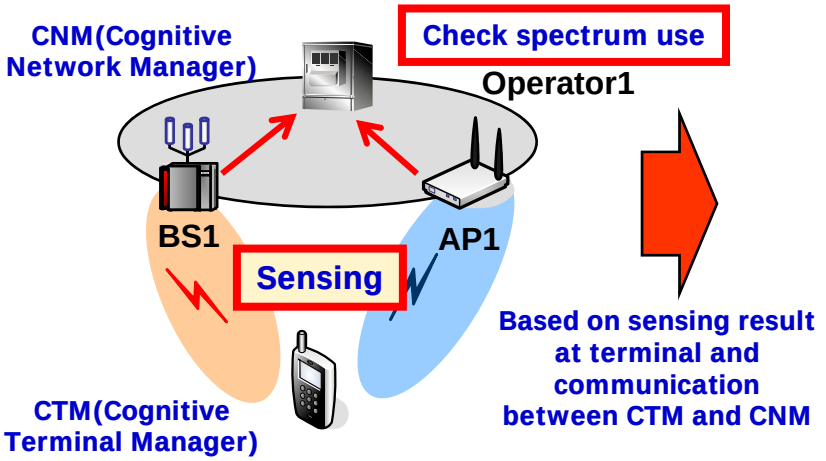
- **Problems** in the policy of future frequency assignment
  - There is no frequency band for future broadband wireless communication systems
  - New method to assign frequency band for newly standardized radio communication systems is needed
  - Several radio communication systems may co-exist in a common frequency band
  - Several operators assigned new frequency band may need to consider sharing of frequency band
  - Reduction of contamination by interference between radio communication systems is needed

- **Needs for Cognitive radio (dynamic spectrum access network)**
  - Cognitive radio is **a radio or system** that senses, and is aware of, its operational environment and can dynamically and autonomously adjust its radio operating parameters accordingly by collaborating wireless and wired networks
  - Cognitive radio technology is used **to assign a new frequency band** for new standardized wireless communication systems
    - Three types: (1)Underlay,(2)Overlay,(3)Aggregation of conventionally assigned systems



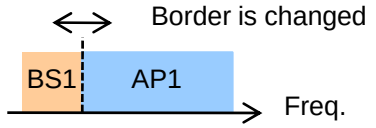
Usage model of cognitive radio technology

Cognitive wireless network in single operator



Network side

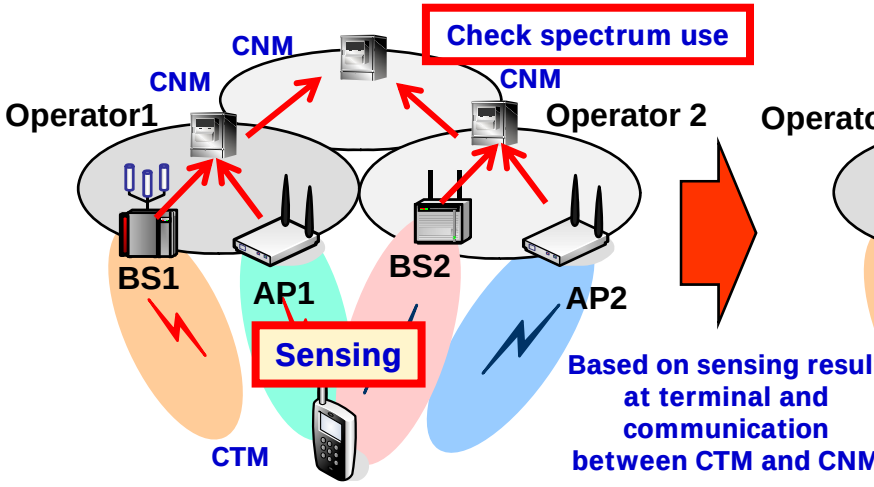
Dynamic freq. allocation to improve QoS for users and/or network operator



Terminal side

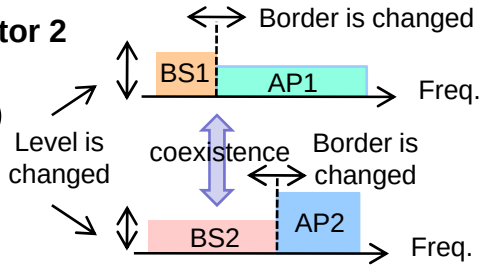
Selection or aggregation

Cognitive wireless network in multiple operators



Network side

Dynamic freq. allocation to avoid interference



Terminal side

Selection or aggregation

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R&D project related to cognitive radio technology

R&D project funded by Ministry of Internal affairs and communications (MIC)

R&D project by National Institute of Information and Communications Technology (NICT)

R&D on elemental technologies for advanced radio spectrum sharing on mobile communication system
Period: Dec. 2005-March 2008

Research and development on software defined cognitive wireless network
Period: April 2006-March 2011

R&D on cognitive radio communication technology

Research body: **KDDI Corp., KDDI R&D Labs Inc, Hitachi, Ltd., Mitsubishi Electronic Corp.,ATR**

Research theme:
- Media-independent operation with cognitive radio technology
- Autonomous inter-base station network with cognitive radio technology

R&D on elemental technologies for cognitive radio terminals

Research theme :
- Multi-band and tunable devices for cognitive radio hardware platform
- Hardware platform for cognitive radio terminal
- Software platform for cognitive radio terminal

R&D on key technologies for Software Defined Cognitive Radio (SDCR) equipment

Research theme :
- Baseband signal processing architecture
- Software architecture based on software defined radio technology
- Sensing algorithm
- Reconfiguration algorithm

R&D on software defined cognitive wireless networking and its related technology

Research theme:
- System architecture
- Functional architecture
- Common signaling architecture
- Link aggregation/ selection algorithm

Cognitive Wireless Cloud (CWC) Project by NICT

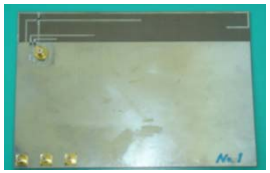
Introduction of R&D results

- Following 3 main R&D results are introduced
  - **Cognitive radio equipment** (by NICT)
    - Multiband and tunable devices for hardware platform
    - Software platform
    - Cognitive radio equipment
  - **Cognitive wireless network in single operators** (by KDDI and Hitachi)
    - Media-independent operation with cognitive radio technology
    - Autonomous inter-base station network with cognitive radio technology
  - **Cognitive wireless network over multiple operators** (by NICT)
    - System architecture of **cognitive wireless cloud** (CWC)
    - Carrier(or Operator)-independent operation with cognitive radio technology
    - Common signaling system
      - Outband dedicated common signaling system
      - Inband common signaling system

R&D activity on cognitive radio equipment

- Multiband and tunable devices for Hardware platform-

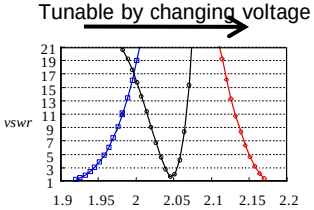
Develop **multiband and tunable devices** to sense radio operational environment over UHF to 6GHz band and develop hardware platform

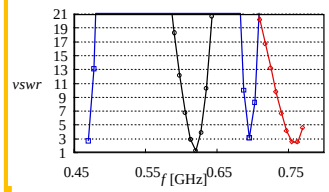


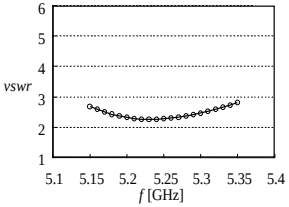
Inverse F type multiband and tunable antenna with variable reactors

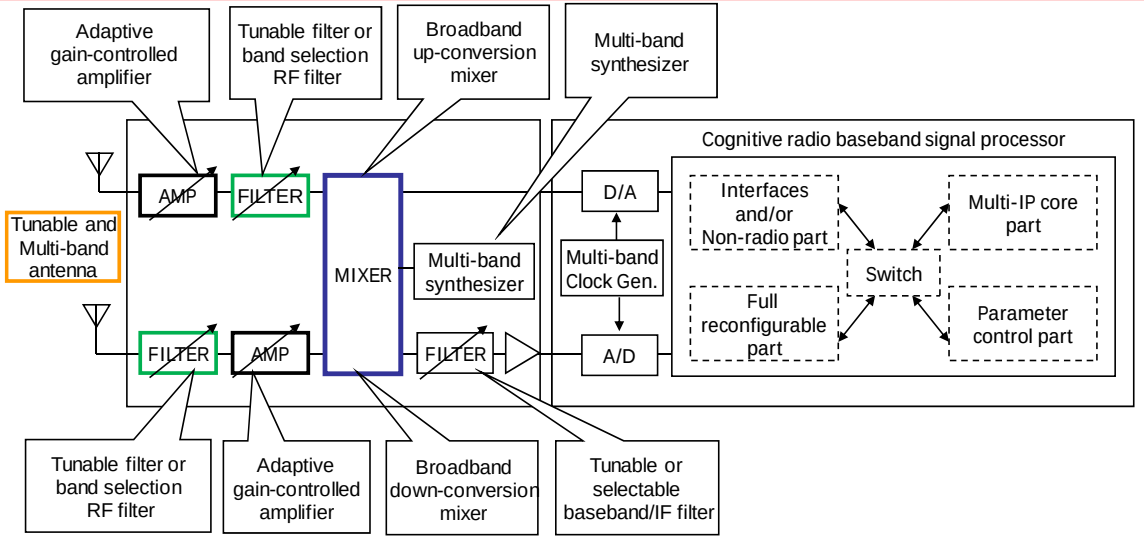
Tunable multiband antenna

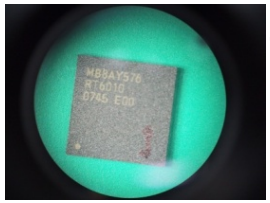
Tunable by changing voltage







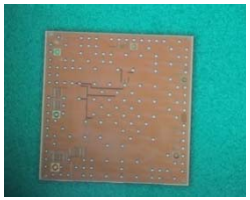




Tunable broadband amp.

9mm x 9mm

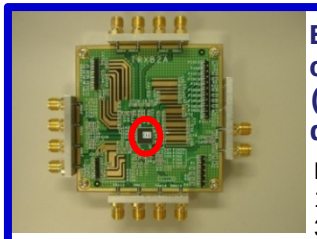
- Tunable frequency band : 0.4-6.2dB (2 mode)
- Gain (variable): MAX 30dB
- MAX output : 24dBm
- NF:5dB(typ.), MAX 10dB
- Process: 90 nm RF-CMOS
- Power supply: 3.3 V



9mm x 9mm

Tunable Bandpass filter

- Tunable frequency band:
  Mode 1: 0.4～0.8 GHz
  Mode 2: 0.8～1.3 GHz
  Mode3:1.3～2.1 GHz
  Mode 4: 2.1～3.0 GHz
  Mode 5: 3.0～4.0 GHz
  Mode 6: 4.4～6.0 GHz
- 3dB bandwidth (variable) :
  Mode 1: 250～600 MHz Mode 2: 400～1300 MHz
  Mode 3: 400～1500 MHz Mode 4: 600～2000 MHz
  Mode 5 600～2000 MHz Mode 6: 500～3250 MHz
- Attenuation performance: 30dB/oct
- Insertion loss: MAX 3.5dB
- Process: 90 nm RF-CMOS
- Power supply: 3.3 V



Broadband direct conversion mixer (Up-conversion and down-conversion)

Frequencyband:0.4-5.8GHz,
180nm SiGe BiCMOS
3.3 V

- TX OP1dB: larger than -18 dB
- TX EVM: less than 3% (rms)
- RX NF:
  less than 5dB@ 400 MHz and 2GHz bands
  less than 15dB@ 5GHz band
- RX dynamic range to meet EVM of less than 11%:
  larger than 50dB@400 MHz and 5GHz bands
  larger than 60dB@2GHz band

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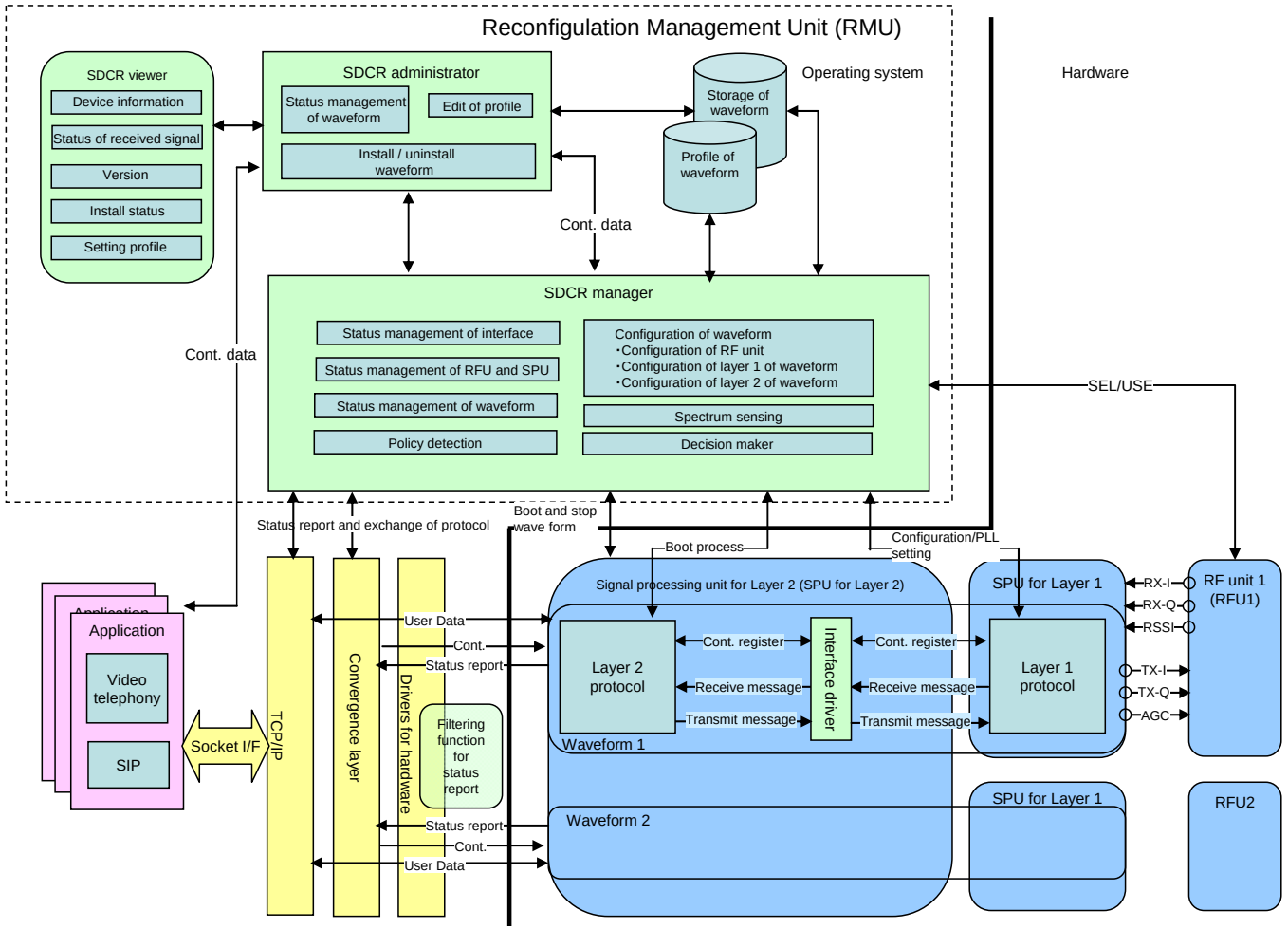
R&D activity on cognitive radio equipment

- Software platform-

Develop software platform that includes functions of sensing, learning, and decision making (select adequate communication systems) **on the widely-spread operation systems**



Software Defined Cognitive Radio (SDCR) manager

- Sense spectrum from layer 1 and 2 modules and store the sensing info. to the memory
- Manage sensing status of RF unit (RFU) and Signal processing unit (SPU)
- Show the list of available communication systems
- Manage status of available radio communication systems using sensing info.
- Decide policy for dynamic spectrum usage by including the status and user preference
- Reconfigure layer 1 and 2 modules by using software defined radio technology

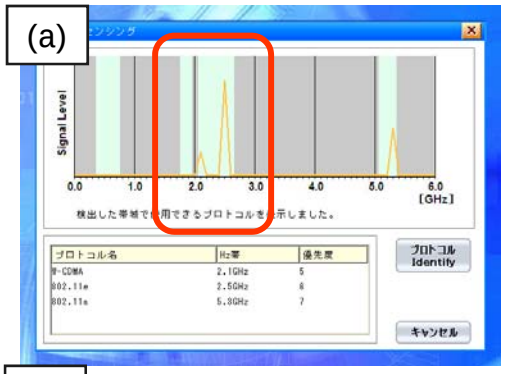
Software platform is operated on LINUX and uITRON

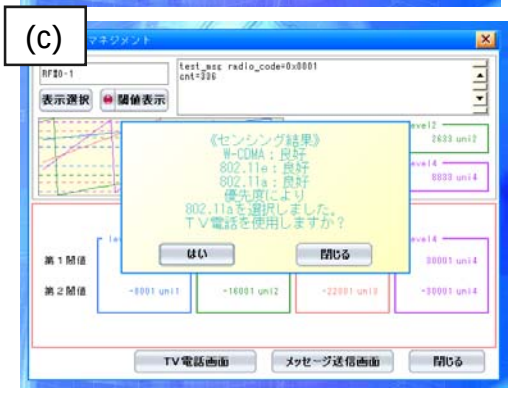
R&D activity on cognitive radio equipment

- Cognitive radio equipment -

- **Sense spectrum over UHF to 6GHz band** and show spectrum usage –(a)
- **Indentify communication systems in selected frequency band** by using software defined radio (SDR) technology –(b)
  - Set a target frequency band
  - Install a software module that realizes a communication system and reconfigure radio equipment-(*)
  - Change frequency band
  - Measure RSSI, BER, FER (Layer1), and connectivity (Layer 2) for each communication system
  - Identify whether the installed communication system is in the target frequency band or not
  - Back to (*) and install other software module for other communication system
- **Show available and connectable communication systems** –(c)
- **Select favorite communication systems and start communication** –(d)

Include baseband processing board
and multiband RF board





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R&D activity on cognitive wireless network

- Cognitive wireless network in single operator -

HITACHI
Inspire the Next

Media independent operation with cognitive radio technology

Key technologies:

(1) Smart environment recognition

Cognition of radio environment with Frequency / Time / Space / User conditions

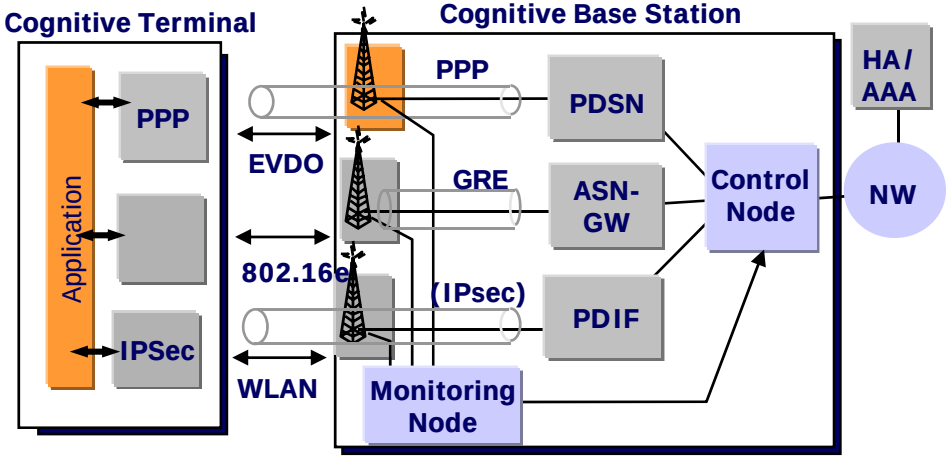
(2) Cognitive radio resource management

Network load balancing with dynamic resource assignment

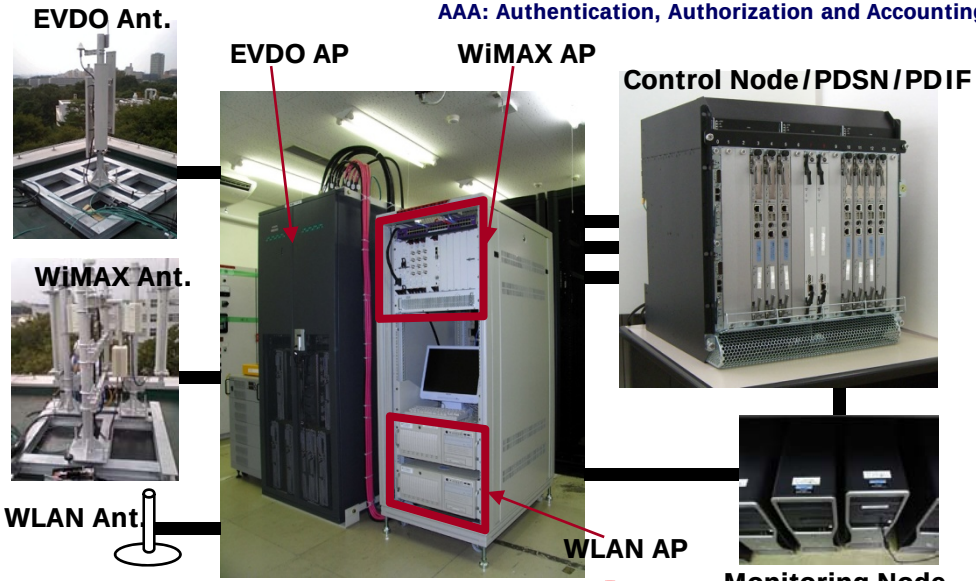
(3) Integrated platform for inter-system HO

Multi-system integration architecture with control node and monitoring node

System Architecture and Testbed Overview



PDSN: Packet Data Serving Node, HA: Home Agent
ASN-GW: Access Service Network Gateway
PDIF: Packet Data Interworking Function
AAA: Authentication, Authorization and Accounting



Results:

- **Experiment with testbed System**

Developed a testbed system that supports EVDO, WiMAX and WLAN, and have evaluated a performance of the testbed system under multi-user environment.

- **Construction of integrated platform**

Developed a smart environment method by “Monitoring node” on the platform: Based on information from “Monitoring node”, “Control node” decides system switching.

- **Evaluations with the simulator**

Developed a simulator that supports EVDO, WiMAX, and WLAN and evaluated the performance from radio environment recognition and resource management points of view.

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R&D activity on cognitive wireless network

- Cognitive wireless network in single operator (cont') -

KDDI R&D LABS

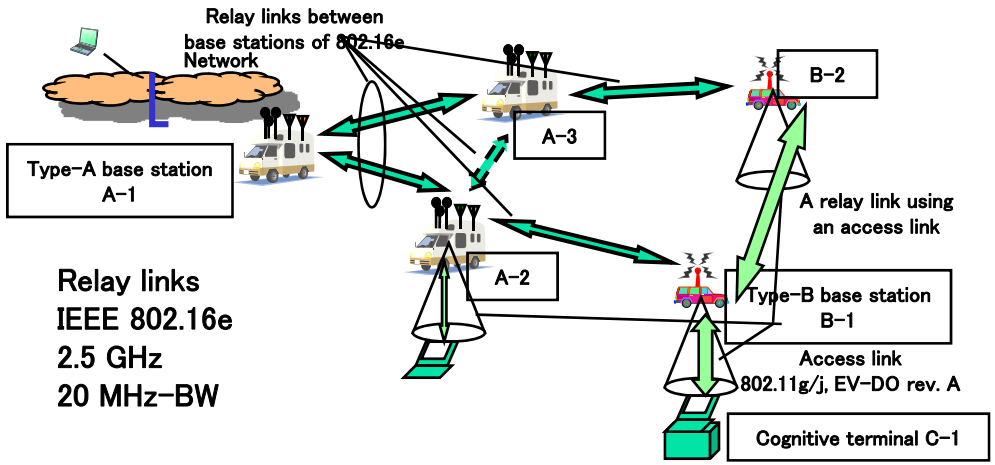
Inter-base station network using cognitive radio technology

·Objectives

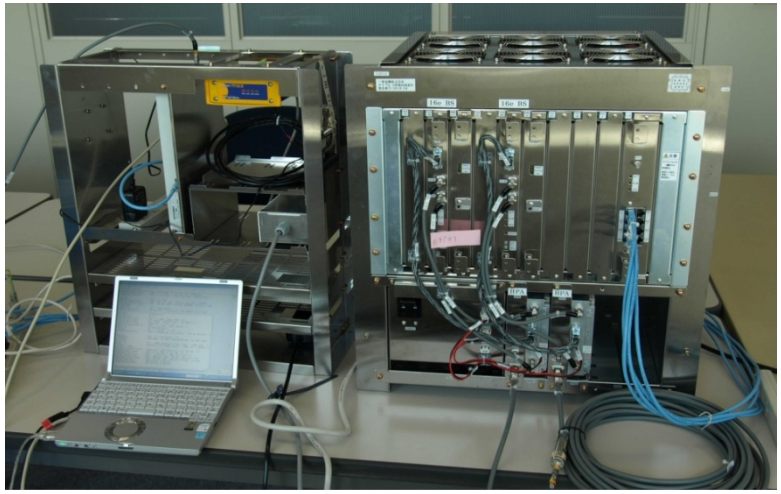
- Development of experimental inter-base station network based on cognitive radio technology
- Field trial with the developed system
- Measurement of characteristics of radio transmission, interference avoidance control, performance of IP transmission

·Technical study components

- Autonomous interference monitoring and route control of inter-base station network
- Location sensing scheme of a signal in a base station equipped with multi-beam antenna
- Efficient use of frequency resource over multiple radio links of broadband transmission
- SDR-based equipment with channel monitoring function



Field trial: Experimental inter-base station network



Field trial: Equipment of base station A-1

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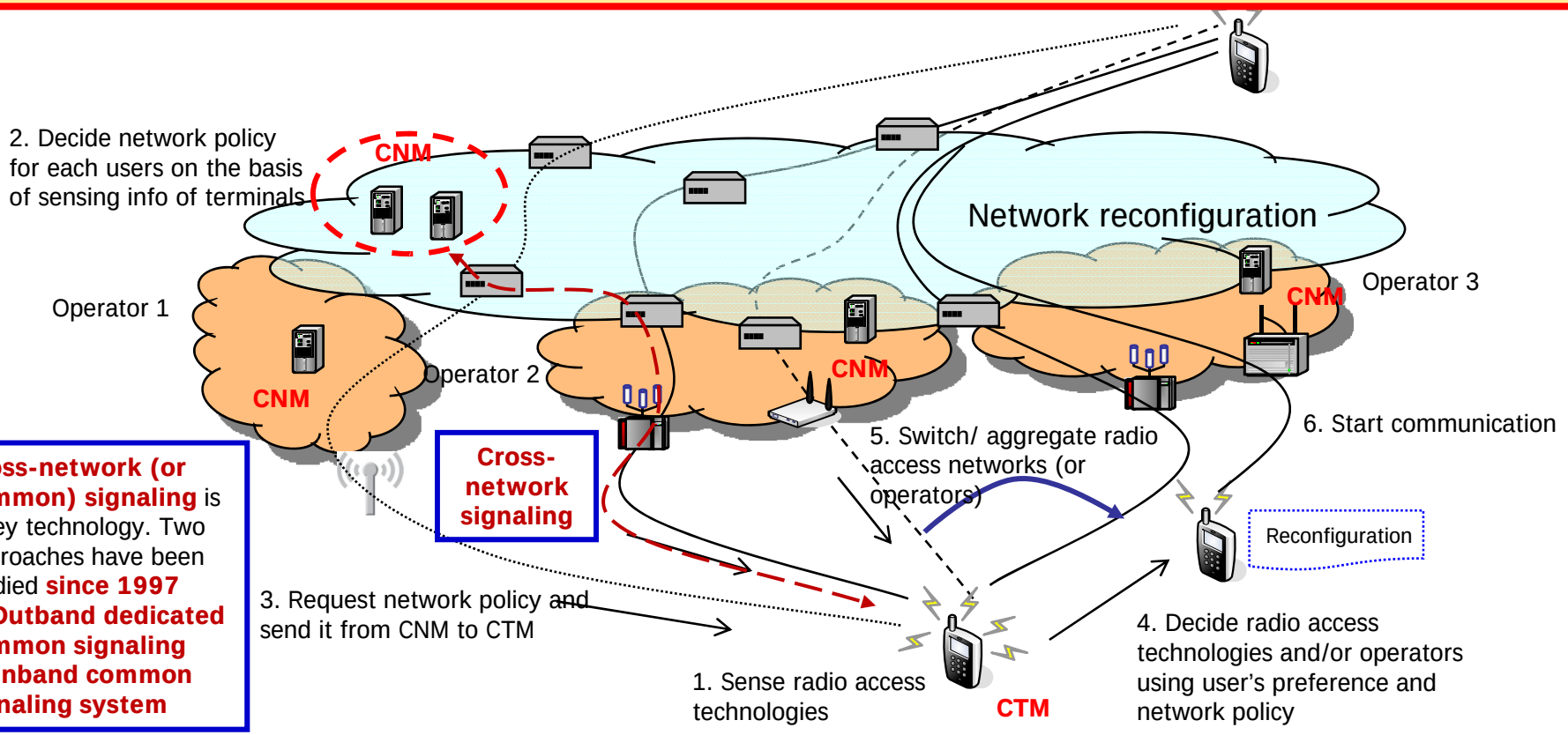
R&D activity on cognitive wireless network

- Cognitive wireless network over multiple operators (for Type 1) -

Cognitive Wireless Cloud (CWC): A cognitive wireless network that decides optimal radio access networks (or operators) and radio access technologies based on collaboration between **Cognitive Terminal Manager (CTM)** and **Cognitive Network Managers (CNMs)** via **Cross-network (or common) signaling**.

CWC includes

- **User-centric network selection:** Using info of CNM and CTM, each user decides communication systems
- **Carrier (operator) independent operation:** Link aggregation and radio selection over multiple operators
- **Scalability:** Easy to add new radio access networks, operators, and radio access technologies



Cross-network (or common) signaling is a key technology. Two approaches have been studied **since 1997**

- **Outband dedicated common signaling**
- **Inband common signaling system**

R&D activity on common signaling

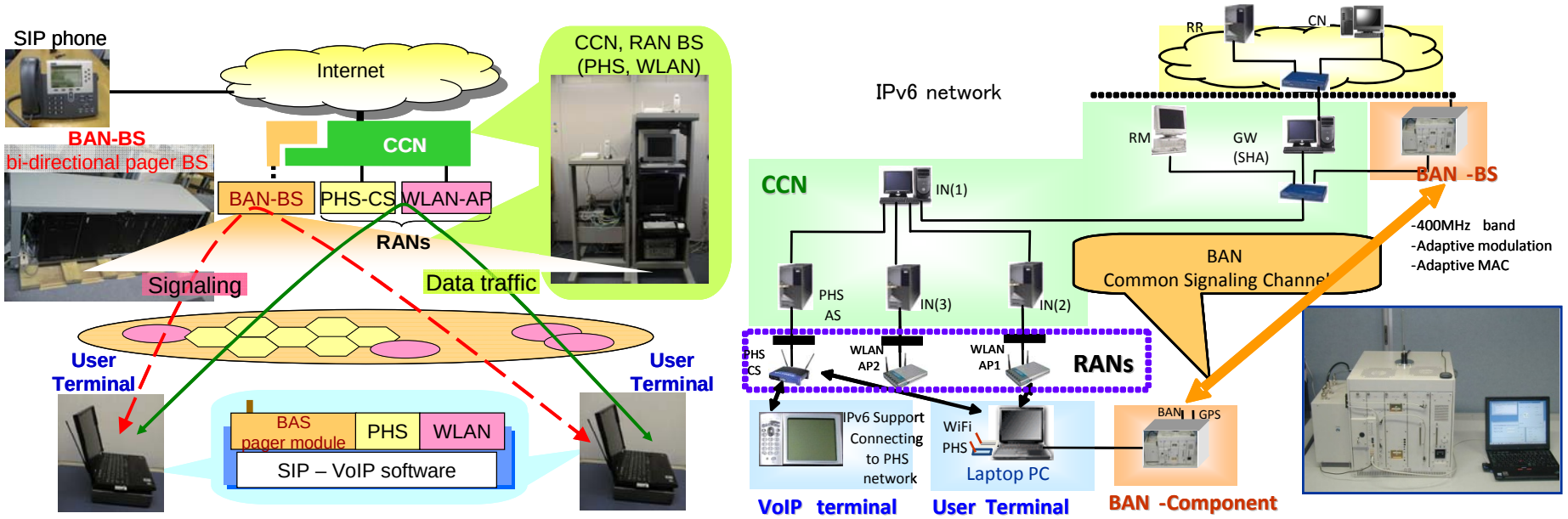
- Outband dedicated common signaling system -

- Outband dedicated radio system for common signaling
  - Signaling data is transmitted to the user terminals over common dedicate frequency band as basic access network
  - The signaling path is not equal to data path
  - Demonstration system has already been developed
  - Reference

World-first R&D results on outband Common signaling system

[1] Y. Hase et.al., "A Novel Mobile Basic Access System Using Mobile Access Signaling Card On Telecommunication Systems (MASCOT), " IPSJ SIG Notes. MBL, Vol. 97, No. 72, pp. 37-42, **July 1997**.

[2] G. Wu et al., “MIRAI Architecture for Heterogeneous Network,” IEEE Communications Magazine, Vol. 40, No. 2, **Feb. 2002**.



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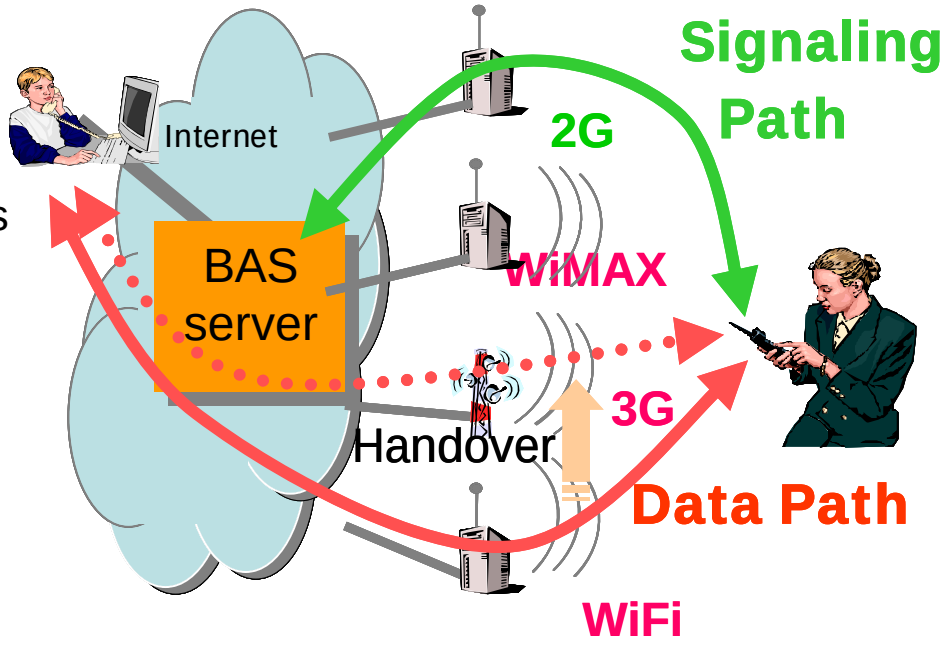
R&D activity on common signaling
- Inband common signaling system -

- Inband common signaling system
  - Signaling data is transmitted between Basic Access Signaling (BAS) server and user terminals over existing communication channel
  - Conventional radio access system is adopted as the communication channel to transmit signaling data
    - Normally the communication systems that cover large communication area may be selected
  - In some cases, the signaling path may not be equal to data path
  - Demonstration system has already been developed
  - Reference
    - H. Murakami et al., IEICE Communication Society Conference, B-5-125, pp.422, **Sept. 2002**
    - M. Inoue et al., IEEE Wireless Communications, pp. 56-63, **April 2004**.

World-first R&D results on inband Common signaling system



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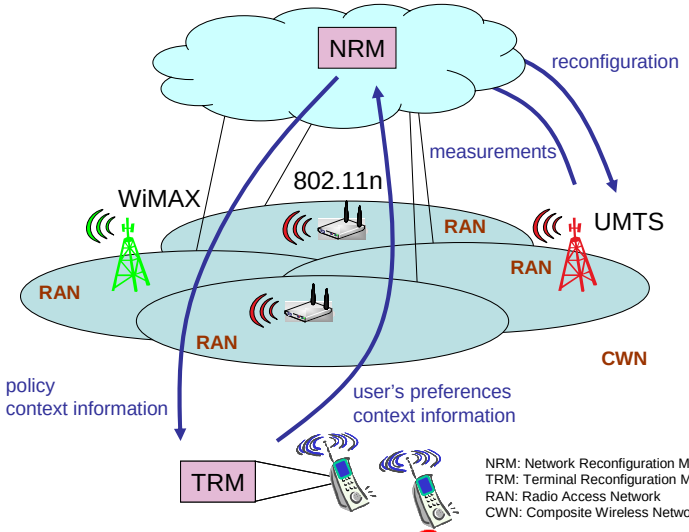
Standardization activity on cognitive radio technology

- **ITU WP5A**
  - Contribution papers based on the results of cognitive radio project funded by MIC have been submitted
- **IEEE 1900.4** (launched Feb. 2007)
  - The purpose is to improve overall composite capacity and quality of service of wireless systems in a multiple Radio Access Networks (RANs) environment, by defining an appropriate system architecture and protocols which will facilitate the optimization of radio resource usage, in particular, by exploiting information exchanged between network and mobile terminals, whether or not they support multiple simultaneous links and dynamic spectrum access.
  - **22 entities** have voting right (entity based voting)
  - **More than half contributions** are currently given from **NICT** as follows:
    - Meeitng#1 (Feb. 07): 4%
    - Meeting #2 (Mar. 07): 8%
    - Meeting #3 (June 07): 31%
    - Meeting #4 (July 07): **54%**
    - Meeting #5 (Oct. 07): **69%**
  - Current status: **Baseline document D1.2** has been released
  - **CWC architecture** is compatible with the P1900.4 draft standard



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Conclusion

Japan is one of the leading countries of the R&D on cognitive radio and always contributes to the standardization bodies by introducing the results

- Summarize needs for cognitive radio
  - Cognitive radio is used to obtain and assign frequency band for new standardized wireless communication systems
- Summarize two usage models for cognitive radio
  - Cognitive wireless network **in single operator** and **in multiple operators**
- Introduce current ongoing project on cognitive radio
  - R&D project **funded by MIC** and R&D project **by NICT**
- Introduce three main R&D results
  - **Cognitive radio equipment** (by NICT)
    - Fundamental R&D on multiband and tunable devices over 400MHz-6GHz are successfully finished
      - Antenna, amplifier, bandpass filter, direct up- and down- conversion mixer
    - Software platform
      - Based on software defined cognitive radio (SDCR) manager, fundamental functions for cognitive radio such as sensing and decision making are well worked
    - Cognitive radio equipment: world-first software defined cognitive radio
      - Sense over 400M-6GHz and identify communication systems and decide adequate communication systems
  - **Cognitive wireless network in single operators** (by KDDI and Hitachi)
    - Media-independent operation with cognitive radio technology
    - Autonomous inter-base station network with cognitive radio technology
  - **Cognitive wireless network over multiple operators** (by NICT)
    - Introduced concept of **cognitive wireless cloud** (CWC)
      - User-centric network selection, carrier (or operator) independent operation, scalability
    - Common signaling system: **fundamental world-first research has been finished by NICT**
      - Outband dedicated common signaling system :originally developed by NICT
      - Inband common signaling system originally developed by NICT
- Introduce standardization activity on cognitive radio technology
  - **ITU WP5A**: Many contributions are input from the results in national project
  - **IEEE 1900.4**: more than 50% contributions are given from NICT

Contact address and acknowledgement

- Contact address
  - Hiroshi Harada, Ph.D.
    Research manager,
    New Generation Wireless Communication Research Center,
    National Institute of Information and Communications Technology,
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  - Hitachi