Heterogeneous Wireless Networks for Reliable Communications

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Abstract— **This paper introduces the latest status of our undergoing project aiming at reliable communications by heterogeneous wireless networks. This project is one of the new Research and Development (R & D) projects in Japan to attain the efficient use of the precious and scarce radio spectrum resources. A test-bed facility has been developed and their features, specifications and some experimental results are also described. Our project focuses on cooperative heterogeneous wireless networks to improve the reliability of the radio communication links while ensuring efficient use of radio spectrum resources.**

Keywords- heterogeneous wireless network; cooperative radio; cognitive radio; reliability; efficient use; radio spectrum

I. INTRODUCTION

We have recently encountered a serious lack of radio frequency resources with the rapid deployment and world wide expansion of wireless communication systems such as cellular phones, especially those less than 6 GHz because they are suitable and heavily utilized typically by cellular or mobile communication systems.

Under such circumstances, in order to ensure the frequency resources for vital mobile communications, it is necessary to carry out cutting-edge technical research and development (R & D) to enable the effective and efficient usage of limited frequency resources. One approach to achieve efficient use of frequency resources is to allow secondary system(s) to utilize those frequency allocations, such as the well-known TV white space, when they are not used by the primary system(s). Our approach to achieve the efficient use of frequency resources cooperatively utilize the radio resources of multiple co-existing different communication schemes in some frequency bands, which is generally called heterogeneous radio communication. Different radio communication schemes in different radio environments may have different radio link quality such as reliability. Therefore, by cooperative selection of different communication schemes offered in certain areas, higher reliability and efficiency is achieved than those served by a single communication scheme.

We have performed R & D on the Cognitive Radio System (CRS) [1] under contract organized by the Ministry of Internal Affairs and Communications (MIC) of Japan since 2005 and have developed some techniques for efficient use of radio spectrum resources [2-7].

As the advanced activities of the CRS R &D, we have been successively engaged in new R & D project concerning cooperative heterogeneous radio networks for reliability improvements [8], also under contract organized by the MIC in Japan. In this project, we are focusing on the simultaneous improvement of the link reliability and spectrum efficiency by means of cooperative heterogeneous wireless networks, which select one or more among different communication schemes in some frequency bands on the basis of the advanced sensing of the surrounding radio environments.

Herein, our project overview is described in Section II. In Section III, as an output of this project in the first year, developed test-bed and its key features are introduced. After some experimental results in Section IV, conclusions are finally stated in Section V.

II. PROJECT OVERVIEW FOR HETEROGENEOUS WIRELESS NETWORKS

A. *Project Objective*

The target of our project is to establish key technologies realizing both of efficient spectrum use and reliable radio link. Improvement of the reliability usually costs some resources such as transmit power and/or spectrum. However, in heterogeneous wireless networks, we think the improvement of the link reliability can coexist with that of efficient spectrum usage. For example, when users who can access multiple radio networks select less crowded or stronger radio network for their communications, spectrum is more efficiently used than in the case of single radio network. In other words, traffic load is balanced among multiple access networks, which leads to the efficient spectrum use. Then we have a degree-of-freedom to decide which users use which radio access networks for the load-balancing. The reliability performance is the criteria for that decision. By cooperative multiple radio networks, this research aims at the comparable reliability performance to wired communications, together with the characteristics of importance and urgency.

Furthermore, as a future target, we will evaluate the reliability as a function of the attainability of data packets and the time probability of user satisfaction of the radio link quality of service. Concerning such evaluation characteristics, we have so far the following final objectives at the end of project.

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- Reliability: by cooperating *N* communication systems, to improve the attainability of packet arrival by more than *N*-th multiple, which has the necessity of urgent transmission, compared with the case of a single communication scheme,
- Frequency use efficiency: by cooperating *N* communication systems, to reduce the outage time probability of service by less than 1/*N*-th multiple, compared with the case of a single communication scheme.

B. Concept of the Heterogeneous Wireless Networks and Research Items

Figure 1 shows a concept of the heterogeneous wireless networks. There are three different wireless communication systems, or radio access networks (RAN), RAN1, RAN2 and RAN3 co-exist, for instance. The user terminal can monitor and access those three RANs. The RAN itself also monitors the radio environmental condition such as signal strength or traffic congestion. Such information collected both at terminal and base station sides are gathered at the resource managers which select a RAN to be used among the three RANs. There are three research issues as follows.

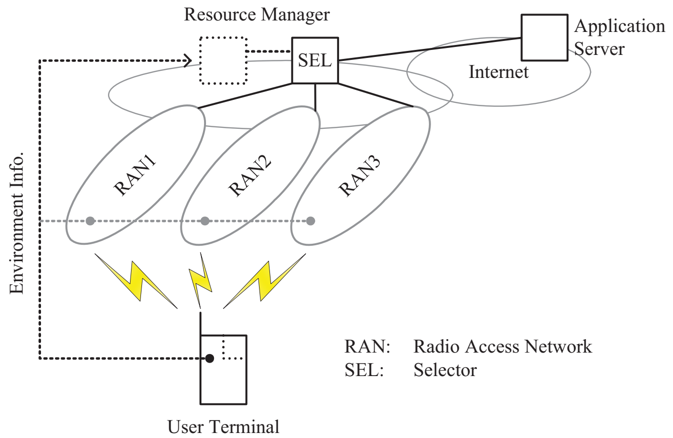

Figure 1. Concept of heterogeneous wireless networks

1) Quality control technique of cooperative heterogeneous wireless networks

To precisely control the link quality of heterogeneous radio systems, we will study the following:

- Advanced sensing techniques to acquire status of the surrounding unstable radio environment, which varies time to time,
- Integrated radio resource controlling techniques to enhance service reliability by cooperating the scheduler schemes of each communication system.

2) Asymmetric link configuration technique of cooperative heterogeneous radio networks

Supposing asymmetric configuration of the communication link and traffic flow in the up- and down-link, we will investigate the following:

- Advanced technique of radio resource utilization by treating the transmitting and receiving links separately.

3) Cross layer coordination technique of cooperative heterogeneous radio networks

Considering a variety of application features, we will study the following:

- Technique to offer the radio quality appropriate to each feature of the application, by means of the cooperation of the upper and lower layers, in which information of the radio environments is conveyed to the application layer.

C. Project Schedule

Our R & D project has a four-year plan. As the first year in the 2008 fiscal year, basic study of the network architecture, controlling sequence and configuration of resource manager and so forth have been performed and manufactured a test-bed for this project which is shown in later part of this paper. In fiscal year of 2009, basic evaluation of the controlling scheme of the link quality, sensing scheme of radio environment, asymmetric communication link and so forth has been researched. Finally, in 2011 fiscal year, we will manufacture a trial system of totalized cooperative heterogeneous wireless networks and its evaluation system, and conduct a field trial of the systems which may include the facilities developed in other research organizations.

III. TRIAL MANUFACTURING OF A TEST-BED

A. Key Features

The studies for the above three research issues obtained so far are described as follows. Based on the study results, we have been proceeding with trial manufacturing of three different systems of communication equipment including the LTE, WiMAX and WiFi, shown in Figure 2. Herein, the LTE, WiMAX and WiFi correspond to RAN1, RAN2 and RAN3 in Figure 1, respectively.

1) Quality control technique of cooperative heterogeneous radio networks:

We obtained the following study results:

- Architecture to cooperatively and equally control heterogeneous radio systems,
- Unified data format exchanging between the database for radio system selection and the RMC (RAN Measurement Collector),
- Refreshment of data base that is triggered by the acquisition of new IP data so as to avoid the issue of unnecessary query to the Data Base.

2) Asymmetric link cofiguration technique of cooperative heterogeneous radio networks

For the purpose of providing the best uplink and downlink simultaneously, symmetric configuration with regard to the resource manager has been adopted both at the network side and the user side, which realizes independent RAN selection for uplink and downlink.

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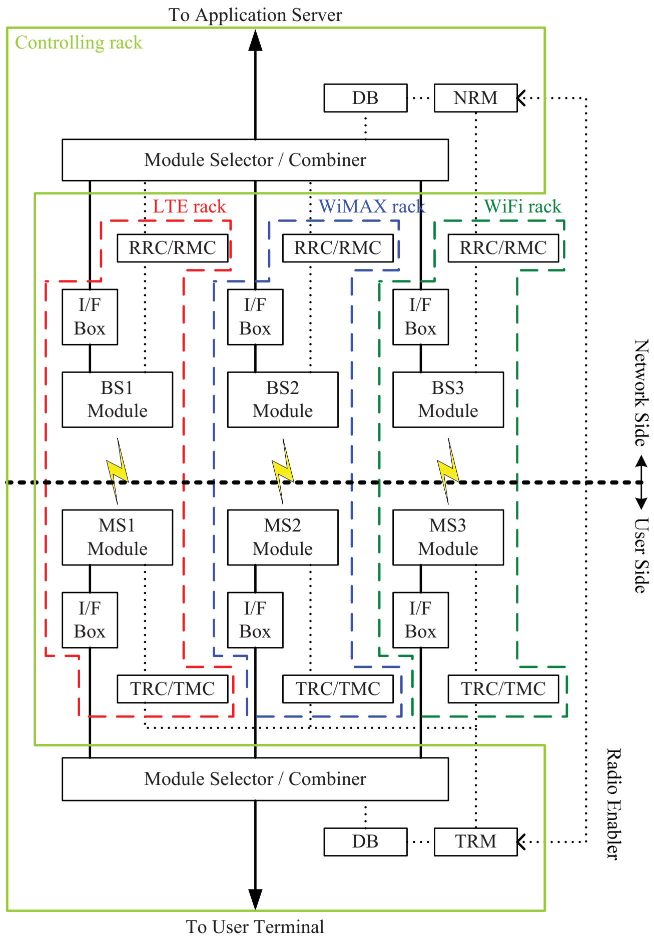
3) Cross layer coordination technique of cooperative heterogeneous radio networks

For a quicker information acquisition for system selection from the application server, we adopted

- A database configuration obtaining such information in session level.



DB:	Database for radio module selector
NRM:	Network Reconfiguration Manager
TRM:	Terminal Reconfiguration Manager
RRC:	RAN Reconfiguration Controller
RMC:	RAN Measurement Collector
TRC:	Terminal Reconfiguration Controller
TMC:	Terminal Measurement Collector
MS:	Mobile Station
BS:	Base Station

Figure 2. Functional blocks of the test-bed.

B. Outline of test-bed

In Figure 2, the name of the functional block follows the definition standardized in IEEE P1900.4 [9]. The test-bed is schematically composed of controlling equipment and radio communication equipment. The main functions of each block are listed in TABLE I. Basically, the hardware of the test-bed is comprised of modified one of commercially available equipment and the main software is developed for this project.

C. Controlling rack

The schematic block diagram and its specification of the controlling equipment are included in Figure 2 and TABLE I, respectively. Figure 3 shows a photograph of the controlling equipment.

TABLE I. FUNCTIONAL SPECIFICATION OF TRIAL MACUFACTURING TEST-BED

Name of Block	Function
NRM	monitoring of whole heterogeneous network operation
Module Selector / Combiner	Selection of prior radio module based on radio circumstance data / Combining data came from different RANs
Data Base for Radio Module Selector	Generation of priority data based on the radio circumstance information exported from each radio module
RMC	Exporting the surrounding radio circumstance information

From the RMC of each radio module, the information for the communication scheme selection is exported to the DB for Radio Module Selector in a short period in the order of 1 second around, in the unified format of surrounding radio circumstance. The Module Selector will select the prior radio module based on the internal radio circumstance data registered to the DB by NRM and TRM, which is frequently updated.

The Module Selector will delete the entry of the internal data table, unless the IP data is received within the predetermined time, thus the issue of the unnecessary query to the DB is avoided. The NRM has the function of monitoring the whole heterogeneous network operation of the test-bed.

As for the control scheme, we studied various possibilities. One of them is the utilization of the time occupancy ratio in each radio system. In this scheme, the terminal will measure the time occupancy ratio or receive it from the base station, then the selection of the radio system is carried out using predetermined rules [10].

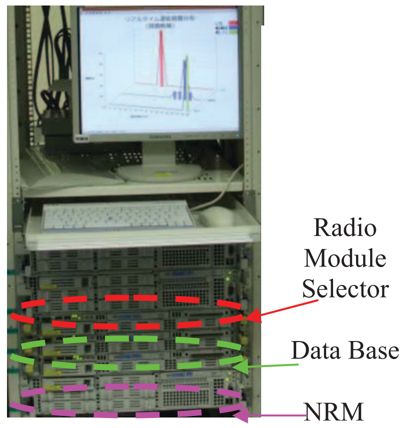


Figure 3. Photograph of the Controlling rack

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D. Radio Communication Equipment

1) LTE rack

TABLE II shows the specification of the physical layer of LTE, which is compliant with 3GPP Rel-8. Figure 4 shows a photograph of the LTE equipment of both the base station and the terminal.

TABLE II. PHYSICAL LAYER SPECIFICATION OF LTE RADIO MODULE

Key Function	3GPP Rel-8 LTE compliant
Frequency	1.9 GHz :UL 2.1 GHz : DL
Bandwidth	20 MHz
Duplexing	FDD
Modulation	QPSK, 16QAM, 64QAM
Data Rate (MAX.)	75 Mbps : DL 50 Mbps : UL

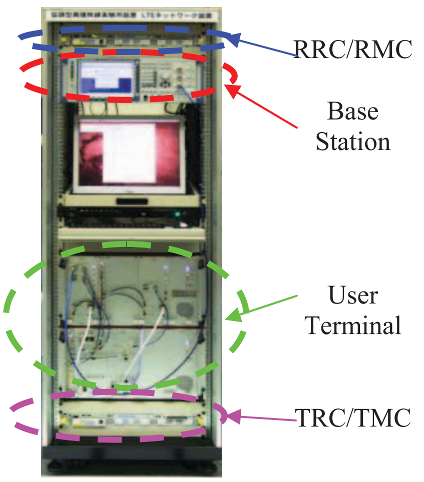

Figure 4. Photograph of the LTE rack

E. WiMAX rack

TABLE III shows the specification of the physical layer of WiMAX, which is compliant with IEEE Std. 802.16e-2005. Figure 5 shows a photograph of the WiMAX equipment of both the base station and terminal.

TABLE III. PHYSICAL LAYER SPECIFICATION OF WIMAX RADIO MODULE

Key Function	IEEE Std. 802.16e-2005 compliant
Frequency	2.5 GHz
Bandwidth	10 MHz
Duplexing	TDD
Modulation	QPSK, 16QAM, 64QAM
Data Rate (MAX.)	18 Mbps : DL 12 Mbps : UL

F. WiFi rack

TABLE IV shows the specification of the physical layer of the WiFi, which is compliant with IEEE Std. 802.11 a/b/g. In the WiFi system, the schemes of 11a, 11b, 11g are switchable in each communication equipment. Figure 6 shows a photograph of the WiFi equipment of both the access point and terminal.

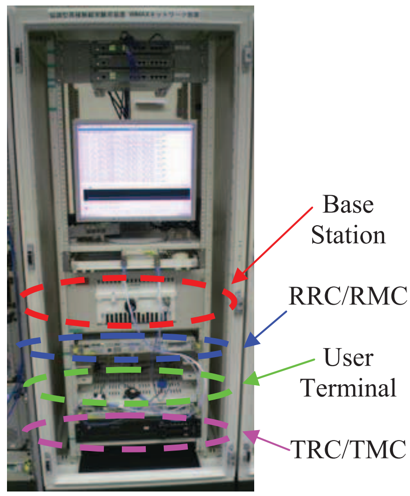

Figure 5. Photograph of the WiMAX rack

TABLE IV. PHYSICAL LAYER SPECIFICATION OF WIFI RADIO MODULE

Key Function	IEEE Std. 802.11 a/b/g compliant
Frequency	5 GHz , 2.4 GHz, 2.4 GHz
Duplexing	TDD
Modulation	QPSK, 16QAM, 64QAM
Data Rate (MAX.)	54Mbps, 11Mbps, 54Mbps,

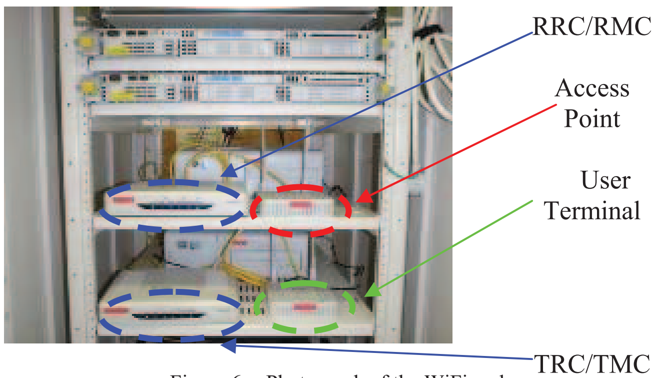

Figure 6. Photograph of the WiFi rack

IV. SOME EXPERIMENTAL RESULTS

In the developed test-bed, RMC in the TABLE I obtains the following transmission related characteristics in each communication equipment, which are exported to the Data Base.

- RSSI (Received Signal Strength Indication)
- Transmission delay
- Time occupancy ratio defined as utilization efficiency index

Radio module selector of the Controlling equipment described in Section III C selects one of the multiple wireless

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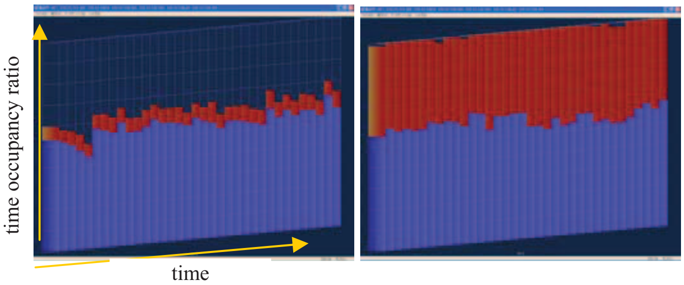
systems such as LTE, WiMAX and WiFi, according to criteria on the above characteristics.

Basic operations of the test-bed have been successfully confirmed. One example of the time occupancy ratio of WiFi system is shown in Figure 7, while the vertical axis depicts the time occupancy ratio of a certain channel.



(a) one user (blue) occupies most of a channel

(b) two users (blue and red) share a channel almost in equal

Figure 7. Example of time occupancy ratio (WiFi)

Figure 8 shows the distribution of measured real time delay of the WiFi, LTE and WiMAX respectively in terms of the cumulative probability in a certain span by moving average, while the vertical axis is the probability and the horizontal axis the measured RTT delay in msec.

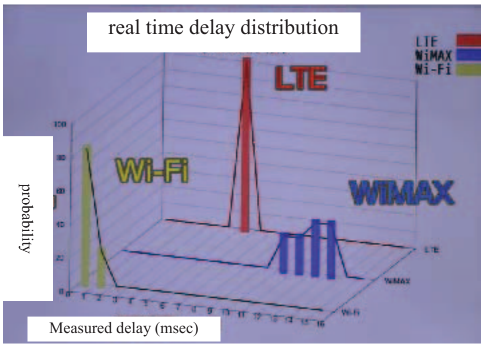


Figure 8. Distribution of measured real time delay

V. CONCLUSIONS

This paper introduces our research activities on heterogeneous wireless networks. The target of the research is to improve the link reliability and the spectrum efficiency simultaneously by cooperative multiple radio networks. In first year of the project, an architecture of the heterogeneous networks was studied with three research issues and a test-bed system was developed. We also confirmed the fundamental behavior of the system. As a next step, we are investigating problematic or expandable issues in our first year results to take a further step toward our target.

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