Multi-Radio Cooperation Technology and Heterogeneous Network Convergence

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Abstract:
The heterogeneous network convergence is the trend of future network development. However, many bottlenecks exist in the converged system such as high time delay, high energy consumption, and low data rate. Multi-Radio Cooperation (MRC) technology is specially designed to overcome these bottlenecks and to satisfy the requirements of heterogeneous network convergence. MRC can improve network capacity, reduce the energy consumption of radio devices, and decrease handover latency between heterogeneous networks by the cooperation of multiple radios, and by efficient management and feasible allocation of multi-radio resources. MRC makes real seamless heterogeneous network convergence possible.

With the development of wireless network technologies, a number of new wireless heterogeneous networks emerged, such as the cellular mobile communications network, satellite network, General Packet Radio Service (GPRS) system, Wireless Local Area Network (WLAN), Mobile Ad hoc Network (MANET), Wireless Fidelity (Wi-Fi) system, and Wireless Sensor Network (WSN). Can users in those new heterogeneous networks communicate with each other? Can users of wireless networks access the Internet? Failure in communications among those heterogeneous networks will result in many isolated information islands of different sizes in the future, which is against our will. Therefore, it is an inevitable trend of network development in the future to implement the seamless connection of diversified heterogeneous networks, which is the heterogeneous network convergence. Network convergence, explained in detail, adopts common open technologies to realize integration of different networks or Network Elements (NEs)[1]; the convergence involves the aspects of access networks, core networks, terminals, services and operation and maintenance.

Heterogeneous network convergence has great advantages in many fields:

- It can expand the network coverage and strengthen its scalability;
- It can fully utilize the current network resources to reduce operation costs and enhance the competence of operators;
- It can provide diversified services to meet various users' demands in future networks;
- It can enhance the reliability and anti-attack ability of networks.

Targeting different applications and users, heterogeneous networks are different from access on the bottom layer to resource management and control on the upper layer. Multi-radio technology will play an important role in the convergence of many kinds of heterogeneous networks using different technologies (especially access technologies).

Multi-radio equips single node in a wireless network with multiple individual radio systems, each of which uses different access technologies and channels. In this way, one wireless network node can establish connection with different access systems simultaneously or it can keep more than one connection with one access system simultaneously. The developments of hardware technology and cost decrease make it possible to realize multi-radio system[2].

MRC technology, through cooperation of multi-radio systems, management of multi-radio interfaces and resource allocation, can reach the goal of cooperation among heterogeneous networks. The technology can enhance network capacity, reduce energy consumption, strengthen mobility management, expand connection range, and finally realize interconnection and interworking of heterogeneous networks.

1 Status Quo of Technologies for Heterogeneous Network Convergence

In recent years, people have proposed several solutions to heterogeneous network convergence:

- BRAIN proposed an open architecture based on convergence of WLAN and Universal Mobile Telecommunication System (UMTS);

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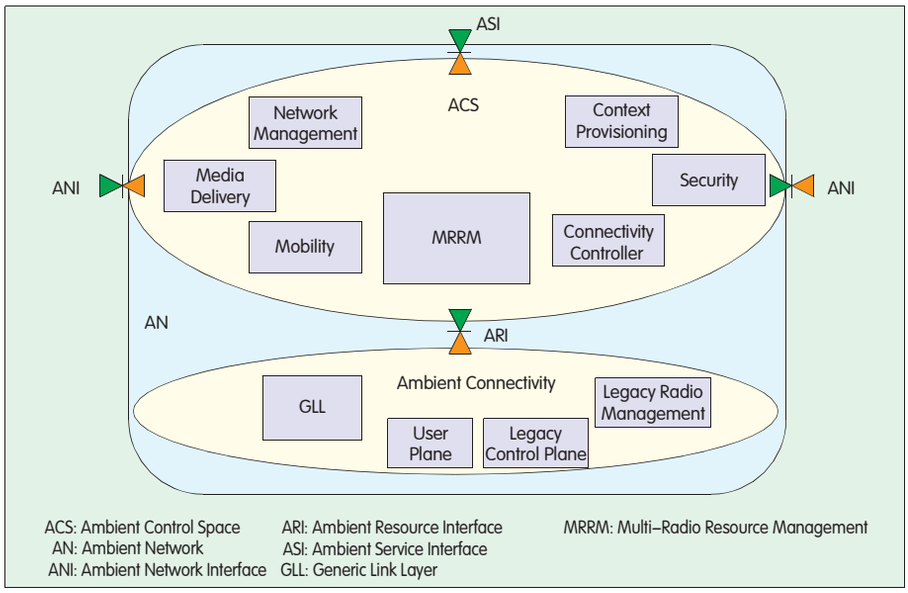


▲Figure 1. AN architecture.

• The DRiVE project studied the convergence of cellular and broadcast networks;

• WINEGLASS studied WLAN and UMTS convergence from the users' point of view;

• MOBYDICK focused its research on the convergence of WLAN and IPv6-based mobile networks;

• MONASIDRE first defined the module for heterogeneous network management.

Though these solutions present different ideas and methods for network convergence, they are still far away from the target of heterogeneous network convergence[3]. The Ambient Network (AN)[4] and Wireless Mesh Network (WMN)[5], recently proposed, provide broader room for research on heterogeneous network convergence.

1.1 Ambient Network

AN is a brand-new network concept based on dynamic composition of heterogeneous networks. It does not improve the current system by simple assembling different networks, but provides users with the ability to access any networks (including mobile personal networks) through setting instant internetwork protocols. One AN element consists of Ambient Control Space (ACS) and AN connectivity modules, as shown in Figure 1.

ACS is comprised of a series of control function facilities, which support Multi-Radio Access (MRA), network connectivity, mobility, security and network management. ACS modules of different ANs communicate with each other through the Ambient Network Interface (ANI) and handle various applications and services through the Ambient Service Interface (ASI). ACS has the Multi-Radio Resource Management (MRRM) and Generic Link Layer (GLL) modules, as shown Figure 2.

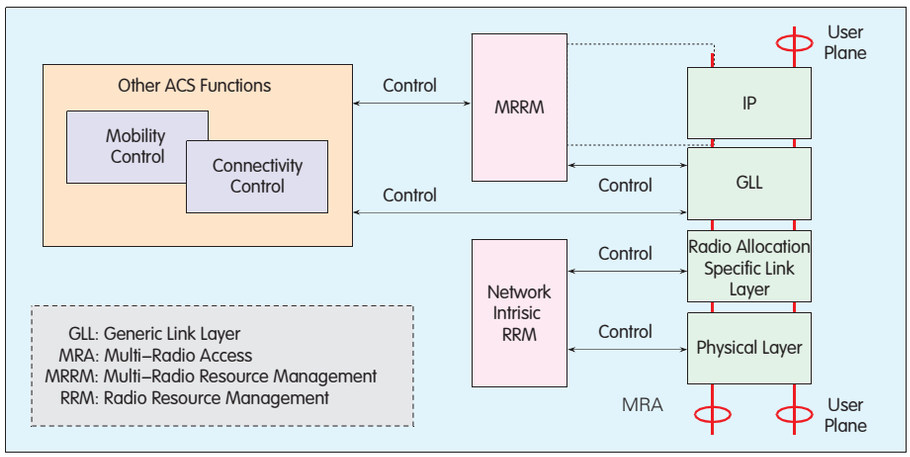
AN is characterized by its MRA technology. The application scenarios of MRA technology in heterogeneous network convergence are shown in Figure 3. MRA technology enables terminals to keep multiple individual connections with one access system simultaneously; it can fulfill seamless connection and multihop data transmission of terminals among different ANs to increase the coverage of AN.

As the first step for AN to realize interconnection of heterogeneous networks, MRA and its resource allocation and management play an important role in ACS, the core component of AN. They are the foundation for any user-oriented heterogeneous network services.

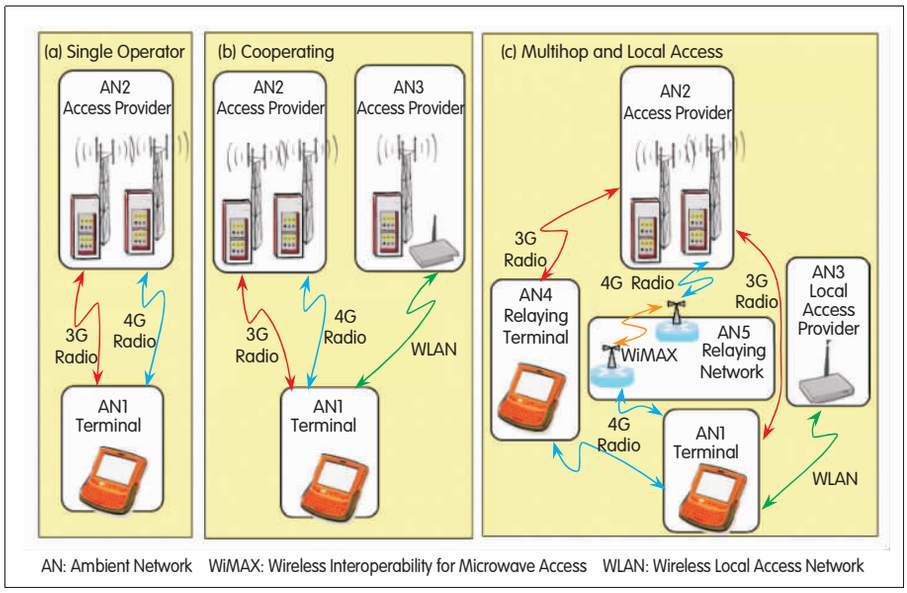
MRC technology, which main function is to realize resource sharing among multi-radio and dynamic inter-AN cooperation, is the extension and development of MRA technology. Other functions of MRC include effective information broadcast and radio access discovery and selection. Besides, MRC allows users to send and receive data simultaneously as they use the multi-radio interface, and supports multi-radio multihop communications.

1.2 Wireless Mesh Network

WMN technology provides a new way to fulfill heterogeneous network convergence. WMN is a wireless multihop system that has mesh networking. Each node in WMN can automatically select route and only communicates with adjacent nodes, therefore, such network is also a self-organizing, self-managing, automatically restoring and self-balancing intelligent network. As shown in Figure 4, WMN implements heterogeneous network convergence through a Wireless Mesh Backbone (WMB) that connects wireless



▲Figure 2. Ambient Control Space working process.



▲Figure 3. Application Scenarios of MRA technology based on heterogeneous network convergence.

heterogeneous networks and fulfills communications between wireless and wired networks.

As shown in Figure 4, WMN consists of WMB, composed of multiple interconnected Wireless Mesh Routes (WMRs), and the user part, including various heterogeneous access networks and terminal devices. As the core equipment of WMN, WMR must be capable of connecting network devices with different architectures simultaneously, and coordinating, managing and controlling such multiple connections. MRC technology enables these capabilities; that is why it has become a hot topic in the WMN research.

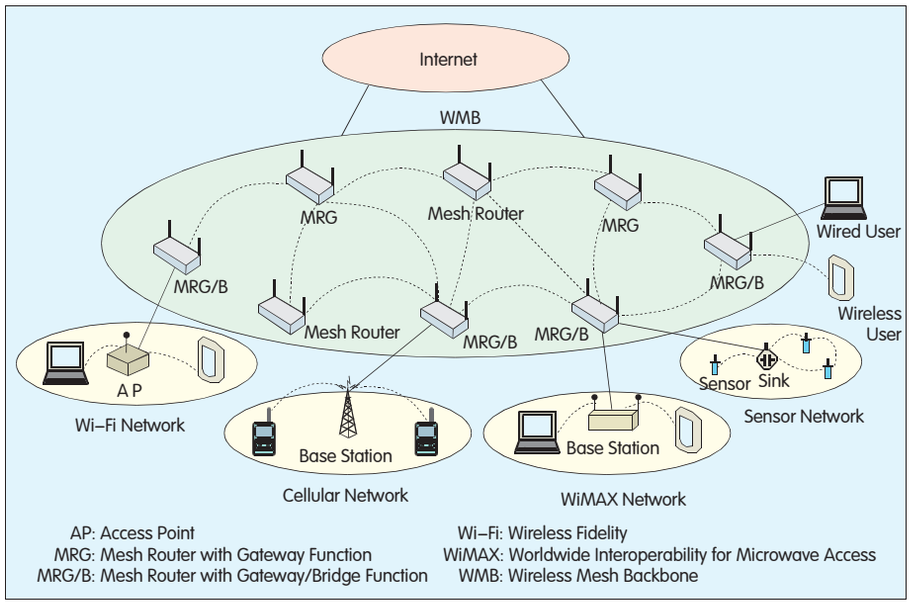
2 MRC Technology Based On Heterogeneous Network Convergence

MRC technology plays a very important role in heterogeneous network convergence, no matter if it is AN or WMN architecture. Through MRC, terminals can keep multiple connections with one access system or connect to different access systems simultaneously; therefore, MRC is better than legacy technologies in the aspect of network capacity, energy control and mobile management.

2.1 Network Capacity

In the wireless network environment, a user's access to a network is always accompanied by transmission interference, multi-user conflict, packet loss and more, so the real working bandwidth is only half of that in theory[6]. Besides, the communication distance between sender and receiver, possibility of node conflict in multihop environment, and hidden and exposed terminals impose great impact on network throughput. Future converged network requires great capacity. Therefore, increasing network capacity is a problem to be solved urgently.

In Document [7], equipped with multi-radio equipment, relaying nodes can send and receive data simultaneously through MRC among nodes. In this way, the transmission delay is reduced. The simulation results show MRC technology can double the network capacity comparing with single radio under ideal situations, and the changes in the number of multi-radios apparently affect the network capacity. Document [8] discusses the relationship between the number of radios and channels, and the impact of radios on network capacity; it deduces the upper and lower limit of network capacity of stationary multi-radio multi-channel networks under random network models. Document [9] presents a method when multi-radio diversity technology is adopted to reduce bit error rate and packet loss rate, so as to increase network liability and further improve throughput of the entire network. The essence of the method is to adopt the diversity technology based on multi-radio multipath cooperation to send and receive data; besides, it uses frame combination and Low-Overhead Retransmission Scheme with Request-for-Acknowledgment (LORFA) to increase the liability and throughput of network. Every Access Point (AP) and user terminal node in the network using this technology are equipped with multi-radio system; any AP receiving



▲Figure 4. WMN-based heterogeneous network convergence.

flawed data frames will utilize the diversity technology based on multi-radio multipath cooperation to send the copies of received data frames to Multi-Radio Diversity Combiner (MRDC) with multiple individual radio equipment. MRDC restores the frames through frame combination technology, and uses LORFA mechanism to resend them to AP; then AP send them to terminal users. The simulation results show that the throughput of multi-radio system can maintain at 15–20 Mb/s in 80% of transmission processes, while that of single radio system can only maintain at 5–15 Mb/s.

2.2 Energy Control

In the future, heterogeneous networks will be required to have higher data rate, more functions to offer more services simultaneously, and hardware with more powerful processing capability and storage capacity, which will consume massive energy. Therefore, energy inevitably becomes the bottleneck for new technology development.

Available energy saving technologies and solutions work by improving channel access mechanism, maximizing sleep time of wireless interfaces, or using lowest energy consumption level to send and receive data. However, most studies are carried out under single radio environment. Document [2] presents a MRC technology with wake-up function to serve the saving energy purpose. With such technology, each mobile device is equipped with two radio receiving and sending devices: Low Power Radio (LPR) for sending and receiving control messages and High Power Radio (HPR) for sending and receiving data. When the equipment is idle, the HPR is off, and LPR is on in order to monitor burst messages. When sending data, a message is sent by the upper layer to LPR, the wake-up function of which will trigger the HPR to receive and send the data packet from the upper layer. When receiving data, LPR will process the request for receipt and send the processed request to HPR and wake HPR up. HPR does not consume much energy in this way. Research shows that such MRC technology has more advantages over other technologies in energy saving. In Document [2], MRC technology with wake-up function is developed and added with control and bandwidth judgment functions. The control function further decreases the time delay caused by wake-up function, and the judgment function enables LPR to transfer low-bandwidth data without switching on HPR. Both functions can save energy.

2.3 Mobile Management

Mobile management includes location management and handover mechanism[10]. Currently the handover technology includes horizontal and vertical handover. Horizontal handover refers to a mobile station in one network switching from one base station to another. Unlike the horizontal handover, vertical handover refers to users switching from one network to another network. Vertical handover technology is the foundation for heterogeneous networks to realize seamless connection. In heterogeneous networks with different radio access technologies, there is much difference in data rate, frequency spectrum, QoS, security, cost and service support. It is extremely complicated to realize accurate location detection and quick handover in heterogeneous networks. However, the study on vertical handover is far less than enough.

Reasonably designed handover mechanism must also guarantee the consistency of service by enabling quick switching when users roam between heterogeneous networks, and ensure the high quality of service by selecting the best connection when users are in the coverage of multiple access networks. Traditional single access method, though single radio device is re-configurable and multi-module enabled, normally causes great delay and high packet loss rate since each network node is equipped with only one radio. Such traditional technology can not meet the requirement of users anymore due to its negative impact on the wireless access and connection for terminal users.

A typical vertical handover procedure includes the following three steps:

(1) Scanning or Detecting

In this step, terminals judge and select the AP with the best link properties by detecting beacon packets sent by APs.

(2) Authentication

Users exchange authentication information with the AP to ensure access security in this step.

(3) Handover Fulfillment

In this step, users register in the new AP. Besides, a corresponding notice message is sent to the original AP, and users' cache information in the original AP is obtained.

Document [11] shows that 90% of the time delay during handover process happens during scanning. Therefore, it is a critical step in handover schemes to reduce delay during scanning. Document [12] improves the current handover mechanisms, and proposes a multi-scan technology based on MRC to reduce delay during scanning. The technology fulfills seamless handover by collaboration between the two radios. The testbed simulation for this technology shows that the handover procedure with multi-scan technology is hardly delayed, while the same procedure under the traditional single radio environment is delayed 640 ms. It is obvious that MRC technology makes seamless connection under heterogeneous network possible.

3 Future of MRC technology

Lacking related research documents, MRC technology based on heterogeneous network is presently at the starting stage with broad perspective for developing.

Besides the three aspects mentioned above: network capacity, energy control and mobile management, its future research in view of layers will include:

(1) Physical Layer

The most difficult issue in the research is how to design and collaborate multi-radio devices when the physical layer faces so many access systems with different protocols. Another new research subject is how to effectively improve frequency spectrum efficiency by integrating multi-radio technology with frequency spectrum sensing and dynamic frequency access technologies.

(2) Media Access Control (MAC) Layer

The design of MAC protocol for multi-radio technology is the most

important issue, in which reasonable design of the channel allocation scheme and channel resource management strategy is the key to maximize multi-radio advantages.

(3) Network Layer

The core problem to be solved is how to design multi-radio routing algorithm by combining multi-channel allocation technology, in which the most important is to design multi-radio multi-channel selecting parameters. Moreover, multi-radio multipath routing algorithm, multi-radio network topology control and network connectivity are challenging topics for research.

Besides, the hardware and protocol standards for multi-radio technology are far from being mature, and most of the available simulation tools and testbeds cannot directly support multi-radio, which all hinder the research and development of multi-radio. Therefore, in the future research, simulation technology of multi-radio is also a challenging subject to study.

4 Conclusion

Heterogeneous network convergence is the trend for future network development, but the different system architectures and access technologies bring great difficulty to the convergence. With the cost decrease of hardware, it is becoming possible to equip one network node with multi-radio systems. Accordingly, MRC technology emerges, providing an effective method for seamless convergence of heterogeneous networks. The importance of MRC technology in heterogeneous network convergence is analyzed in this article from three aspects: network capacity, energy control, and mobile management. The article further looks into the future of MRC technology. Seen from the current situations, not many researches are carried out for heterogeneous network convergence based on MRC technology worldwide; therefore, the research on this field has broad future.

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Roundup

ZTE Achieves Strong Growth of Bearer Network Products

ZTE Corporation continues to register remarkable growth rate for its bearer network products according to the announcement the company made at the recent "ZTE Bearer Network Workshop Malaysia 2008" held in Malaysia in June 2008.

ZTE bearer network products include IP network products and optical transmission solutions. Last year, its IP network products recorded over 100% growth, with bulk of the sales coming from overseas market. At the same time, the optical transmission business also registered sterling record as sales grew by 71% compared with 2006, topping the industry by exceeding the overall market's 24% growth.

Around 100 well–known experts representing various local telecom operators including TM, Celcom, TIME, U Mobile, Maxis and DiGi gathered at the workshop to discuss network evolution trends and changes in service demand. The operators also recognized ZTE bearer network and service solutions as the most reliable in the industry.