Mesh-Based Network Convergence and Cooperation

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Abstract:
More and more distinctive heterogeneous features are exhibited in wireless networks in multitude of networks, technologies, terminals, operation and management, and more. Effective convergence and cooperation of heterogeneous networks can be achieved through Mesh technology. The IP-based convergence integrates common features of heterogeneous networks, while the cooperation coordinates personalities of the networks. By using the convergence and cooperation, a standardized integration of separated and localized predominant capabilities and resources of heterogeneous networks can be fulfilled to enable the evolution into an ubiquitous and omnipotent intelligent network.

The rapid development of wireless communication technologies has catalyzed the emergence of new heterogeneous networks using different networking technologies, such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Wireless Fidelity (Wi-Fi), Wireless Personal Area Network (WPAN), Wireless Mesh Network (WMN), Wireless Sensor Network (WSN), Ad hoc network, 3G network and B3G network. These networks bring the users profound changes of workstyle and lifestyle. The users are experiencing the convenience of information access brought by the development of communication technologies, but network heterogeneity is increasingly obvious due to the variety of wireless access technologies that are developed for high-rate, broadband and ubiquitous wireless communication networks. In fact, besides wireless access systems, heterogeneous terminals, networks, services and operation management systems are attracting much attention. It is the trend of next generation wireless communication systems to offer access services with wide coverage, broad bandwidth, high mobility and low cost through the integration and interworking of these heterogeneous networks and multi-network cooperation. Therefore, the network convergence and cooperation has received common concerns from operators and other links on the communication industry chain.

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1 Heterogeneity of Wireless Networks

Because of different features of radio frequency bands, various networking access technologies and diversified service demands, the implementations of air interface designs and related protocols for different radio technologies are different and incompatible. The heterogeneity of wireless communication networks is presented in the following aspects[1]:

(1) Spectrum Resources

Various physical characteristics of spectrum bands require different types of radio technologies. Moreover, different bands have distinctively different spectrum planning schemes. Accordingly, the radio technology implemented on a special spectrum band has to meet special technology and service requirements.

(2) Networking Access Technologies

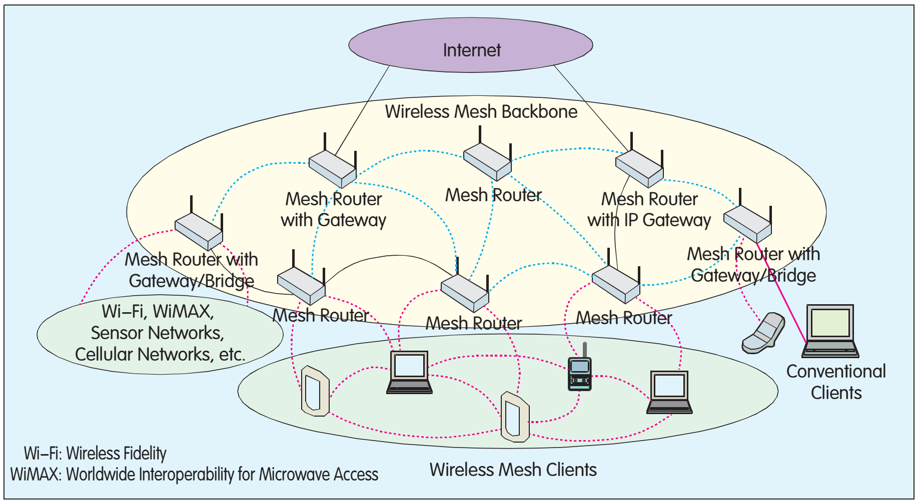
There are greatly different networking models, network function configurations, resource management and configuration schemes for meeting comprehensive requirements of network scale, coverage and compatibility. Different physical layers and Media Access Control (MAC) layers have quite different implementations of modulation, antenna, encryption and access technologies.

(3) Service Demands

Various user preferences and demands lead to the variety of service types, including legacy telecommunication services, transaction services supporting interactive applications and content-oriented services. With different characteristics, diversified services have different Quality of Service (QoS) requirements on technology and terminal.

(4) Mobile Terminals

Heterogeneous networks provide different QoS, which brings huge changes of terminal's working



▲Figure 1. Hybrid wireless Mesh network.

environments. Different service demands, systems and operators lead to the difference in mobile terminals. Various types of mobile terminals have different service capabilities, including access capability and mobility[2].

(5) Operation Management

Different network operators will design different operation management strategies, including those for calling and roaming, handover, resource allocation, authentication and authorization, and billing. In order to fulfill effective interaction of communication layers and to meet networking requirements, it is necessary to design feasible communication protocol stacks and proper network management mechanisms according to radio resources used and service characteristics.

The abovementioned aspects interact with and influence each other. They form the heterogeneity of wireless networks, and bring challenges to network stability, reliability and efficiency. Future communication systems have to solve problems of mobility management, combined radio resource management, and end-to-end QoS guarantee, brought by the heterogeneity.

2 Mesh-Based Network Convergence and Cooperation

2.1 Overview of Mesh Technology

As a new type broadband access network, WMN is originated from the Advanced Tactics Communication System (ATCS) that was proposed jointly by the Defense Advanced Research Projects Agency (DARPA) of the United States Department of Defense and ITT Corporation in 1977, and that integrated wireless networking, routing and positioning functions into one system. The IEEE 802.11 Working Group set up the Mesh Networking Task Group (802.11s) in January 2004, which marked the beginning of WMN standardization. As an important solution to the "last mile" problem of radio access, the WMN technology is attracting increasing attention.

Basically, WMN enables every node in the network to send and receive signals. As a multi-hop system, WMN offers communication path redundancy from the source to the destination. Every node in WMN has an automatic routing function, and only communicates with its adjacent nodes. Therefore, WMN is a type of self-organizing, self-managing, self-healing and self-balancing Intelligent Networks (INs).

There are three types of WMNs: Infrastructure WMN, client WMN, and hybrid WMN. The last architecture integrates the advantages of the former two. As shown in Figure 1, the hybrid WMN architecture can include heterogeneous wireless and wired networks, such as WLAN, WiMAX, wireless cellular network, mobile Ad hoc network, WSN, Internet and wireless backbone network. In fact, WMN has become a superset of mobile Ad hoc network, while the mobile Ad hoc network is just a subset of the WMN. Having all the advantages of WMN, including wide coverage, high spectrum efficiency, good reliability, multi-hop routing, flexible networking, convenient maintenance, and compatibility and interoperability with other wireless networks, the hybrid architecture can be applied into various scenarios, such as broadband home network, community network, enterprise network and Metropolitan Area Network (MAN).

WMN is expected to become an ideal networking solution to wireless Core Network (CN) in the future. In the mobile communications environment with complex network coverage and coexistence of various technology types, the Mesh technology enables effective convergence and cooperation of heterogeneous systems, fulfilling advantage complementation and coordination management of heterogeneous resources. Therefore, Mesh is a certain technology development trend. Besides, it is an ultimate way for network operators to fulfill best user experience and optimal resource utilization[3].

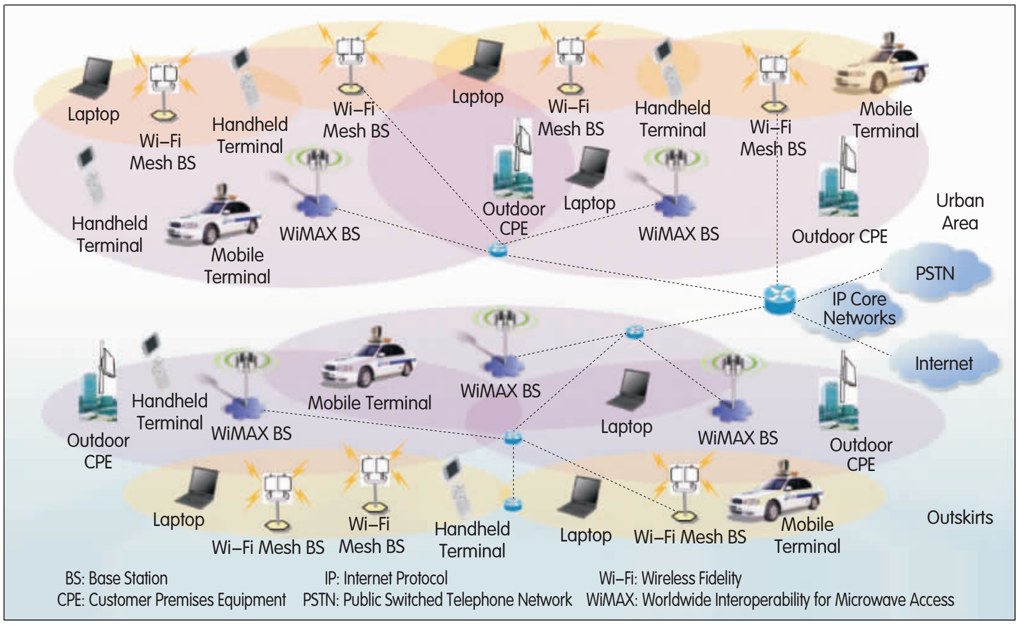
2.2 Mesh-Based Network Convergence

There is no effective coordination mechanism between individual heterogeneous networks, which has brought a series of problems like inter-system interference, overlapping coverage, limited service offering capability of single network, shortage of spectrum resources, and seamless handover of services. Therefore, the convergence of heterogeneous networks has become a leading development trend of various network layers. Presented in network, service, terminal and operation management, the convergence will enable all kinds of services transported in physical media of the converged network, and the interconnection and interworking of IP-based services in different networks by using unified Transmission Control Protocol/Internet Protocol (TCP/IP). The Mesh-based convergence will be fulfilled in the following layers[4-6].

(1) Convergence of CN and Access Network

The wired network based on IP packets has become the infrastructure of the next generation networks. It will provide access networks with proper wired infrastructure networks.

Various mobile access networks, including Wideband Code Division Multiple Access (WCDMA) system, Global System for Mobile communications (GSM) and WLAN, cover different areas, have different technical parameters, offer varied service capabilities, implement different communications and control protocols, and have different network architectures. Therefore, the access networks are required to have capability of inter-network message interaction to support IP-based network convergence. Moreover, terminal reconfigurability enables terminals to access various networks, and the wide application of IP technology make access network convergence implemented at the IP-based network layer. Figure 2 is an example of the WMN application into MAN. In the figure, user terminals, such as Wi-Fi terminals and laptops, interconnect with each other through Ad hoc system, and communicate with either Wi-Fi Mesh Base Station (BS) (IEEE 802.11) or WiMAX BS (IEEE 802.16) according to protocols they support. The Wi-Fi Mesh BS or WiMAX BS may establish connection to either BSs out of line of sight or the Internet CN. In this example, the Wi-Fi Mesh BS and WiMAX BS serve as Mesh routers for the convergence implementation. They also form wireless Mesh backbone networks that are converged at IP layer. Multi-mode or reconfigurable Mesh terminals are used to adapt to demands of users and services. In this way, the entire network is eventually converged.



▲Figure 2. An instance of WMN convergence and cooperation.

(2) Service Convergence

Service convergence will let users experience smooth communications in any situations and enjoy optimal and diversified services by providing different service networks with a unified platform, unified user account and automatic handover mechanism hided from users. In the conditions of limited service support capabilities of networks and terminals, multiple access technologies will be used to provide multiple terminals with diversified services. In Figure 2, although Wi-Fi terminals and laptops bear different services, the IP-layer convergence enables them to access WMN and fulfill interworking of different services.

(3) Terminal Convergence

Heterogeneous wireless networks from different operators may overlap at one place, providing different services and QoS with various charging schemes. The terminal does not need to change its essential elements aiming at this situation, but it is required to be compatible to all the Radio Access Technologies (RATs) coexisting at that place, and comprehensively consider the capabilities of the RATs, network coverage states, charging schemes and user preferences. Software radio based reconfiguration technology can be used for terminals to improve compatibility, reduce terminal sizes, decrease power consumption and save cost. Multi-mode reconfigurable mobile terminals are able to access different mobile networks. For example, the Wi-Fi terminals and laptops in Figure 2 can mutually access data services through the CN; if the terminals are multi-mode and even reconfigurable, they can mutually access more services, such as video and voice services.

(4) Convergence of Operation Management Systems

The converged operation management system will provide users with unified network management and network service interfaces, such as unified Authentication, Authorization and Accounting (AAA), unified subscription and unified bill service.

Network convergence is an extensive research subject. Its true value is how to use advanced technology system to help operators reduce cost, improve operation efficiency and enhance their competence by winning subscribers' recognition. Although it can bring users flexible and abundant service experience, the network convergence has to consider the following issues:

(1) Usability

Besides the increase of usable bandwidth, the network convergence also needs to standardize and control service applications' priorities for resource utilization, in order to solve the problems caused by the growth of service applications, such as incapability of crucial services guarantee and sharp decline of QoS.

(2) Security

Encryption, Virtual Private Network (VPN) and firewall technologies shall be used to prevent hidden troubles in information resource access control and access authorization, and eventually eliminate unprecedented security risks brought by network mobility and flexibility to enterprises. It is necessary to take costs, benefits and security into a compromise consideration.

(3) QoS

Data, voice and video services require different QoS. An IP network with perfect management, abundant bandwidth and good latency feature should guarantee QoS to offer priority to data, voice and video services and meet their requirements on QoS.

Mesh-based handover, Joint Radio Resource Management (JRRM) and end-to-end QoS guarantee are the solutions to the abovementioned problems. They are described as follows:

(1) Handover in Mobility Management

Handover is a special and crucial function in wireless mobile communication systems. The inter-cell handover of mobile terminals in homogeneous cellular networks is called horizontal handover; that is the handover between different access routers based on the same link-layer technology. The mobile terminal's handover between heterogeneous networks is called vertical handover; that is to say, the handover is conducted between different access routers based on different link-layer technologies. To support vertical handover, a mobile terminal needs to have a dual mode card that can work under two different network systems, and even a reconfiguration function.

Vertical handover is the basis of heterogeneous network convergence, and also a crucial feature and core technology of the future mobile Internet. The crucial issue for vertical handover is to design a reasonable handover algorithm to meet service demands of users. Maintaining a low packet loss rate, the handover algorithm should effectively reduce the number of handovers, eliminate "ping-pong effect" (load jitter caused by a terminal's unceasing handover between two or more access points due to terminal's mobility and time-varying feature of wireless channels), improve the handover call blocking rate, and obtain good handover performance. In the all-IP next generation wireless communication system, mobile IP will be employed to handle handover between access networks while cellular IP will be used for intra-access-network handover processing. Such a layered mobility management strategy is worth deep research.

(2) JRRM

Different from the traditional concept of radio resources, heterogeneous radio resources in the future include wireless spectrum, as well as other resources in wireless networks, such as limits of mobile users' access rights, channel coding, transmit power and connection modes. The goal of traditional radio resource management system is to allocate and adjust usable wireless transmission and network resources, improve wireless spectrum efficiency, prevent network congestion, and maintain signaling load as small as possible under the conditions of limited bandwidth, unbalanced network traffic, channel feature fluctuation caused by channel fading and interference. Unlike the traditional resource management, JRRM is a set of control mechanisms for all heterogeneous networks. It will fulfill optimal radio resource utilization and maximum system capacity by employing multiple access technologies, multi-mode or reconfigurable terminals, intelligent call and session admission control technologies, and distributed service and power processing. JRRM can implement all the functions of traditional radio resource management systems.

With Joint Session Admission Control (JOSAC) and Joint Radio Resource Scheduling (JOSCH), the two main functions, JRRM is able to optimize frequency efficiency of heterogeneous networks, process all kinds of service bearers and various QoS requirements of users and services, and conduct adaptive scheduling to hybrid services. JRRM design has two basic features: a tight-coupling model for heterogeneous network interconnection; and traffic diversion function. The JRRM model in future will not be restricted to concentrated management only, but employ concentrated management, distributed management, or layered management that falls in between the former two. JRRM requires the configurability of terminals and even of the entire network to meet the requirements of JOSAC and JOSCH[7].

As an important technology for JRRM, Multi-Radio Access Selection (MRAS) is able to effectively use multi-radio access gains by dynamic management terminal's accessing one or more heterogeneous wireless networks. The multi-radio access gains brought by MRAS include multi-radio access diversity and multi-radio access combining. Moreover, such technologies as load balancing and dynamic spectrum distribution[8] are used for JRRM to adaptively and harmoniously allocate resources among multiple usable wireless networks.

The JRRM-related Generic Link Layer (GLL) based on a reconfigurable platform fulfills cooperation data processing of different RATs. It serves as the convergence layer for multiple accesses, provides the upper layers with a unified interface, and hides the heterogeneity of multiple access networks at the bottom layer. It also transfers context messages on the link layer to the upper layer, implementing seamless vertical handover with no loss between different RATs. One of the important GLL functions is to dynamically swap a data flow from the upper layer into a proper RAT. Then the upper layer completes optimal access path selection, configures or reconfigures GLL by controlling the serving radio resource management module, and make data flows swapped among different RATs[9] according to available radio resources and decision messages from the bottom layer.

(3) End-to-End QoS Guarantee

Since the convergence of heterogeneous networks is completed based on IP, any end-to-end calls originated from the communication terminal with ability of IP connection may not only travel over networks of different operators, but also employ different RATs. Besides, QoS support capabilities and QoS control strategies of different networks may not be acquired before a call is originated. Therefore, perfect end-to-end QoS guarantee in heterogeneous mobile networks first requires IP-based QoS negotiation and joint radio resource allocation mechanism. Moreover, QoS messages of different networks should be expressed

and computed in one system, cross-layer feedback interaction mechanism should be introduced. In this way, adaptive end-to-end QoS guarantee will be eventually fulfilled.

2.3 Mesh-Based Network Cooperation

Network cooperation and convergence are reconcilable. Generally, heterogeneous network convergence integrates the common characteristics of different networks based on technology and concept innovations, while the cooperation integrates personalities of different networks based on technology and concept innovations. The convergence serves for better cooperation, that is to say, the convergence not only guarantees original wireless networks to implement their own functions, but also offers good conditions for cooperation processes such as more advanced function implementations and technology innovations[10-11].

The networks or technologies in operation can offer more functions than the sum of functions of individual networks or technologies. That is, the network cooperation aims at the emergence effect in system theory. The study on Mesh-based network cooperation includes the following subjects:

- The cooperation of different terminals or technologies in an individual wireless network to enhance the performance of individual wireless communication system;
- The cooperation of heterogeneous wireless networks to produce emergence gains.

The heterogeneous network cooperation is not a simple network superimposition or combination, it involves cooperation in spectrum, protocol stacks, air interfaces, services, heterogeneous terminal communication technologies and network security[12-13].

Homogeneous access networks employ advanced cooperation technologies like multi-antenna cooperation, coding cooperation and multi-route convergence cooperation to fulfill intra-network communications. Cooperation processing mechanism is used for inter-network communications of heterogeneous wireless access networks to fulfill interconnection and interworking of the heterogeneous networks, reduce transmission latency and improve the whole network performance. Cooperation relay node selection plays an important role in cooperation communications of homogeneous and heterogeneous wireless access networks. The selection is implemented by node resident, crude cooperation relay selection based on signal strength, fine cooperation relay selection based on multi-goal optimization and power and resource allocation for relay nodes. As in Figure 2, when a mobile phone user in the Mesh network cannot connect to the base station due to special location or signal fading, it can get the cooperation of a Wi-Fi terminal in Ad hoc network through multi-hop and relaying to access the CN and fulfill service communications.

Similar to network convergence, the cooperation can be fulfilled in the following layers:

- A single wireless link uses various channel cooperation technologies, including cooperation Multiple-Input Multiple-Output (MIMO), cooperation coding and cooperation multi-user diversity;
- Through cooperation of multiple users, a single terminal user fulfills high data rate or QoS, and solves such problems in QoS guarantee as transmission latency;
- Wireless access networks can obtain high data rates and eliminate the bottleneck of inter-network transmission through cooperation;
- CNs can fulfill cooperation-based multi-CN convergence.

For establishing an advanced wireless communication network, the cooperation of both terminals and networks is necessary. The development of cooperation, to some extent, is more important than that of convergence in the information field, because cooperation means the emergence of new functions and more technology innovation chances. However, current studies of cooperation mostly focus on primary technologies, and inter-network cooperation is under further research.

3 Ambient Ubiquity Network and Prospect of Network Convergence and Cooperation

Aiming at heterogeneous network convergence and cooperation, similar new concepts have been proposed from Asian and Pacific regions, European Union and North America. Ambient Ubiquity Network (AUN)[14] is one of them. In the AUN environment, network does not passively meet user demands, but positively perceives any changes of user scenarios and positively makes message interaction. AUN initiatively offers services by analyzing personalized user demands. Correspondingly, terminal equipment in AUN has intelligent interfaces and ambient perceptibility, facilitating service users. AUN adds three layers between the legacy network service application layer and network access and bearing layer: network resource abstract plane, AUN control plane, and service support and agent plane. Different from legacy networks, AUN has a unified control plane, supports dynamic network reconfiguration control system, and changes network equipment into resources. AUN offers a nice vision to the future information society with the following characteristics:

- Ambient perceptibility;
- Self-organizing and self-healing;
- Ubiquity and heterogeneity;
- Openness and transparence;
- Mobility and broadband;
- Multimedia and cooperation;
- Symmetry and convergence.

Accordingly, AUN is not a network revolution, but the discovery of potentials in legacy networks and the improvement of network performance efficiency.

The rapid development of radio technologies leads to heterogeneity of communication networks. The networks will evolve from separation to interworking and further from interworking to cooperation. The inter-network convergence and cooperation will fulfill an organic integration of separate and partial network strengths and resources, eventually providing a series of new functions including self-healing, self-management, self-discovery, self-planning, self-adjustment and self-optimization, and making the system more intelligent. AUN holds out the hope of heterogeneous network convergence and cooperation in the future. However, the fulfillment of a real ubiquitous and omnipotent intelligent network still has a long way to go.

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Roundup

ZTE Records Highest Industry Growth for Optical Networking Solutions

ZTE Corporation has the highest industry sales growth in the area of Optical Networking (ON) last year, according to the report published by international research firm Ovum entitled "Market Share 4Q07 and 2007 Global ON". The company's ON products' sales grew by 120% in 4Q 2007 compared with that of 2006, the report revealed. The Ovum report analyzes quarterly results of different ON solution vendors, including ZTE's, and compares that with the sales figures recorded in the previous year.

The Ovum's Optical Networking Market Analysis by segment ranks ZTE second in terms of global market share for LH Dense Wavelength Division Multiplexing (DWDM) and ADM area, proving that ZTE's continuous efforts in investing and developing new optical technology is paying off. Market-wise, Ovum predicts global ON spending to reach $16.4 billion by end of 2008, laying ahead enormous market opportunities and increasing bandwidth demands in all regions.

"It is a significant accomplishment for us that our ON products have successfully penetrated more than 90 countries worldwide, including APAC, Europe, North America, Africa and Middle East. We partner with multinational telecom companies and carriers to deliver high-quality ON solutions that meet the rapidly accelerating demand for high-end optical networking products," said Mr. Han Ling, ZTE' sgeneral manager of optical network products, "ZTE is fully committed to expanding our ON product portfolio in the years to come to address the market needs for higher bandwidth, as well as to sustain sales growth of our optical networking product range."