Study on QoS and Communications Capacity in Heterogeneous Network Convergence

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Abstract:
To provide any subscriber from anywhere at anytime with services that have both secured Quality of Service (QoS) and simultaneous expansion of network coverage and communications capacity is a key problem that has to be considered and solved in heterogeneous network convergence. Key technologies for a secured QoS and communications capacity analysis under heterogeneous environment are important subjects for research. Key technologies for a secured QoS are mainly on radio resource management algorithms covering Call Admission Control (CAC) algorithm, vertical handover algorithm, heterogeneous resource allocation algorithm and network selection algorithm. The applications of a novel multi-hop in heterogeneous convergence system serve the purposes of network coverage expansion, transmission power reduction, system communication capacity and throughput increase.

Heterogeneous network convergence is the trend for next generation network. A key problem to be solved is to provide all subscribers with Quality of Service (QoS) guaranteed services anywhere and anytime. It is necessary to carry out QoS guaranteed key technology research not only for optimizing network resource but also for designing inter-access-network collaboration. As an important study aspect of heterogeneous network convergence, the research currently focuses on resource management algorithms such as Call Access Control (CAC), vertical handover, heterogeneous resource allocation, and network selection. The resource management algorithms for traditional mobile communications networks have been extensively studied and have made abundant achievements, however, such study in heterogeneous network converged system faces huge challenges due to network heterogeneity, user mobility, variety and uncertainty in resource and subscriber demands.

Besides, network coverage expansion, seamless connection and communications capacity increase are the key to the success of heterogeneous network convergence and the premise for different operators to willingly converge their networks. Therefore, communications capacity analysis becomes another key issue for heterogeneous network convergence.

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1 QoS Guaranteed Resource Management Technologies

1.1 CAC Algorithm

Unlike the traditional cellular network for which CAC algorithm has been extensively studied, heterogeneous network convergence system, using multiple wireless access technology and requiring different QoS for multimedia applications, faces great challenge in designing effective CAC algorithm. The following aspects should be taken into account in design and study of the CAC algorithm for heterogeneous network convergence system.

(1) Heterogeneous Characteristics of Different Networks

Heterogeneous network convergence system is supported by multiple wireless access technologies, and different wireless access networks have heterogeneous characteristics. For instance, the cellular network is a wireless network with infrastructure that provides QoS guaranteed service to subscribers through base stations that control and manage subscribers' access to channel resources. IEEE 802.11 Wireless Local Area Network (WLAN) adopts Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technology for channel access; however, IEEE 802.11e standards provide weaker QoS support to real-time services compared to the cellular network, though the standards take into account the real-time channel resource access and enhance QoS guarantee as well. Movement of subscribers between heterogeneous networks causes vertical handover; therefore, when designing CAC algorithm, it is necessary to consider vertical handover, decide its priority and calculate its dropping probability. This dropping probability is an important measure for heterogeneous

network convergence system, and should be limited in an acceptable range.

(2) User Mobility

In the heterogeneous network environment, traditional model assuming even user mobility is no longer applicable, and different mobility of users in different covered areas needs to be considered.

(3) Multiple Service Types

Heterogeneous network convergence system provides multiple service types, which require different QoS guarantee. Real–time services such as voice and video are time–delay sensitive but packet–loss tolerable; non–real–time services are packet–loss sensitive and moderately time–delay sensitive; but best–effort services such as file transmission are packet–loss sensitive but time–delay non–sensitive. Different networks have various capabilities to support different services. The cellular network can provide effective support to real–time services but transfer data at a rather low rate, while short distance communications networks such as WLAN support high data rate but need to improve their support to real–time services.

(4) Cross–Layer Design

In the packet–based wireless network, layer optimization can improve system performance. Therefore, it is necessary to evaluate the QoS performance of the call level (call blocking probability, forced termination probability) and the packet level (packet transmission delay, packet loss rate) through cross–layer design.

Currently, the study of CAC algorithm in heterogeneous network convergence system mainly focuses on the CAC in cellular/WLAN convergence system. Document [1] presents WLAN–first CAC algorithm, which directs originating voice and data calls from the cellular/WLAN overlapping area to the WLAN first and hands over the ongoing voice and data calls to the WLAN whenever WLAN coverage and bandwidth are available. In the WLAN–first algorithm, different characteristics of voice and data services are not fully considered. Document [2] introduces and analyzes a two–layer CAC algorithm of cellular/WLAN convergence system. CAC for wireless access only considers the call admission in the cellular network but not the calls in WLAN. Those algorithms did not take into consideration the abovementioned four conditions; therefore, there is still much research work to do on CAC algorithms in heterogeneous network convergence system.

1.2 Vertical Handover Algorithm

Users' moving between different networks is called vertical movement. Vertical handover, the process to keep continuous user communications when a mobile terminal changes its access point, is the biggest challenge for fulfilling seamless vertical movement. In the heterogeneous network environment, the traditional decision, comparison of signal strength method, is no longer applicable for vertical handover. The vertical handover decision, due to the special characteristics of heterogeneous network convergence system, needs to consider the following factors besides signal strength:

(1) Service Type

Different services require different reliability, time delay, data rate and QoS guarantee.

(2) Network Conditions

Because vertical handover will break the balance among heterogeneous resources, the design of vertical handover decision strategy should make use of network–side information of the system, such as available bandwidth, network delay and congestion condition, to avoid network congestion and to realize load balance among different networks effectively.

(3) System Performance

Characteristics of channel propagation, path loss, co–channel interference, Signal–to–Noise Rate (SNR) and Bit Error Rate (BER) should be considered to ensure system performance.

(4) Status of Mobile Terminal

This includes the terminal's speed, moving model, moving direction, location and more.

(5) Price

Because different networks use different charging methods and price standards, price becomes one of the essential factors affecting handover decisions.

(6) User Preference

Different users prefer differently, which also affects handover decision.

At present, the study of vertical handover algorithm concentrates on strategy–based design[3–4] and decision design based on fuzzy logic theory[5–6], which can hardly adjust the heterogeneous resources in networks at the same time guaranteeing satisfaction of user demands. The Common Radio Resource Management (CRRM) system studied by the 3rd Generation Partnership Project (3GPP) is limited because its access network selection only considers network load, and it only aims at cellular networks such as Universal Mobile Telecommunication System (UMTS) and GSM EDGE Radio Access Network (GERAN). Therefore, it has weak capability of managing and controlling heterogeneous resources.

Therefore, the abovementioned factors should be taken into account when designing vertical handover algorithm. Vertical handover design should give attention to both QoS and adjustment and allocation of heterogeneous resources during and after the handover. However, taking a comprehensive consideration of all decision factors will definitely increase the complexity of handover process and make the decision on handover more difficult. The theories such as multiple attribute decision making and cost function[7] can evaluate different decision factors at the same time, and may accordingly be used for vertical handover strategy design in heterogeneous networks to guarantee users' QoS and optimize heterogeneous resource allocation.

1.3 Heterogeneous Resource Allocation Algorithm

The resource allocation algorithm for heterogeneous network convergence system needs to effectively control the access of various real–time and non–real–time services to wireless resources; it is also required to handle burst services, random arrival of packets, random number changes in packet switching connection, and more. Those factors, including various user demands, changeable channel quality, and

diversified network operators, will be the situation for a long time in the future, which decides that the networks might adopt loose–coupling schemes for convergence. Therefore, it is necessary for heterogeneous network convergence system to adopt novel distributed dynamic channel resource allocation algorithms, which is important to guarantee QoS and enhance the network performance.

In accordance with users' QoS requirements and network situations, the dynamic adaptive channel resource allocation algorithm dynamically adjusts bandwidth allocation. It, if possible, allocates more channel resources for calling to enhance user's QoS; when the network congests, it makes room for more calls through reducing channel resources for accepted calls, reducing the system call blocking rate and forced termination probability, and increasing the utilization rate of system resources and user QoS.

It is essential to establish a system model for deep research of the channel allocation algorithm in heterogeneous network environment, but no general system model has been released yet. Most published documents use the stimulation method to make analysis, or only build models respectively for individual networks in the converged system. Mathematic methods such as Markov model, matrix computation and queue theory can be used to build a multi–dimensional and multi–area system model for heterogeneous network convergence system, obtain different status of the system model under different algorithms, and further derive system performance and compare different algorithms.

1.4 Network Selection Algorithm

The heterogeneous network convergence system usually takes three steps to fulfill a user's network selection:

(1) Collecting necessary for network selection decision information, such as user's preference, service type, and network conditions.

(2) Entering the above information into the network selection algorithm, which should ensure best QoS for the user anywhere and anytime.

(3) Selecting network according to the algorithm output.

Many researchers have presented their network access selection algorithms, such as random access[8] and high bandwidth priority[9]. But these algorithms only consider the user side or overall network capacity, only applicable for single user situations. There are no mature proposals for access network selection of multiple users under the heterogeneous environment.

Since the current algorithms are not applicable for multiple users and lack consideration of heterogeneous resources, it is necessary to closely analyze the requirements and characteristics of network selection in heterogeneous network environment, and carry out research on corresponding data information models according to the principle of multiple layer collaboration (physical layer, link layer, network layer, and application layer). Confined by the characteristics of heterogeneous networks, optimizing a single performance measure through traditional single target decision theory can hardly produce a perfect solution to optimize all the user required targets. Such a problem can be treated as a multiple target optimization issue, and the multiple targets decision theory may be introduced to find a balanced proposal under limited resource conditions. The balanced proposal should be the final satisfying solution after comparing all the valid solutions when selecting access. It has the following advantages:

- Designing the access network selection algorithm for multiple users, so as to increase the algorithm's adaptive capability to the heterogeneous network environment;
- Scalable;
- Favorable for dynamic collaboration of heterogeneous resources by taking the available real–time network resources as decision targets.

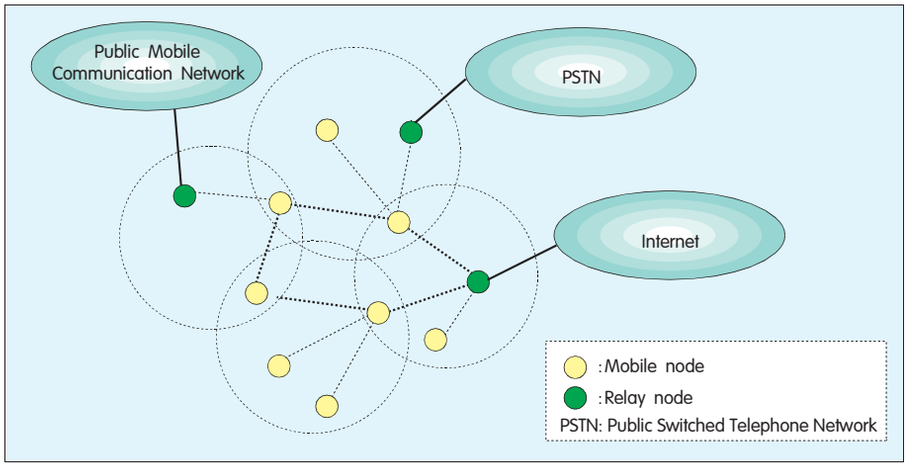
2 Communications Capacity in Heterogeneous Network Convergence System

Novel multi–hop network structure in heterogeneous network convergence system can expand network coverage, increase throughput and system communications capacity. The study on communications capacity of heterogeneous network convergence system mainly focuses on introducing Ad hoc network to cellular–based public mobile communications network.

With the development of wireless communications technology, traditional cellular network face certain problems. For instance, sudden traffic increase in certain an area will cause partial congestion, call drops and outgoing call failures in the area; as a user on conversation enters into the blind area of a cellular network or a user in a blind area sends a new call request, the communications will be interrupted due to failure in receiving signals from base stations. Besides, communications capacity and coverage need to compromise, that is to say, the coverage area of a base station will decrease when network load increases[10].

The Ad hoc network introduced into cellular systems can complement on the coverage defects of the cellular networks. Moreover, the system capacity can be increased by reducing transmission power and interference, which may solve the problem of load balance in hotspot area and realize traffic diversion. As shown in Figure 1, mobile nodes in the network connect to the public mobile communications network, telecommunication network and Internet through multi–hop and relay nodes. Such architecture can also diverse the voice traffic for base stations in a certain congested area (i.e., the hotspot cell) to nearby idle base stations through the multi–hop function in the Ad hoc network, and eventually realize traffic balance.

The study of introducing Ad hoc network into cellular systems has received extensive attention from many international research institutes and academies. The University of New York at Buffalo designed an integrated Cellular and Ad hoc Relaying System (iCAR)[11], using Ad hoc network technology to solve the congestion caused by unbalanced traffic in cellular networks. University of California, Davis, presented a proposal of Mobile–Assisted Data Forwarding for wireless data networks (MADF)[12], which introduced the concept of forwarding agent, using the Ad hoc network technology to forward



▲Figure 1. Ad hoc network is used to fulfill traffic balance in cellular systems.

traffic in a congested cell to nearby non–congested cells. Opportunity Driven Multiple Access (ODMA) is also a multi–hop forwarding technology based on cellular networks. It can provide high data rate for mobile terminals at the cell edge of Time Division Duplex (TDD) cellular networks and increase the covering range for high–rate data services[13].

In the proposals for cellular network and Ad hoc network convergence, the selection of relay nodes has great influence on system communications capacity. The current relay node selection methods include:

(1) Selecting the nodes with lowest interference and the best link quality to the base station after forwarding to reduce interference to nearby cells.

(2) Selecting the nodes with best link gain to the base station.

(3) Selecting the nodes with the shortest distance to the base station.

The three abovementioned methods are usually applied to non–hotspot cells in order to increase the system capacity.

Besides, relay nodes can be located outside the hotspot areas, which is especially suitable for relieving the congestion in hotspots.

Integrating the above methods can dynamically accommodate the changes of network and greatly increase the communications capacity of hotspots in cellular networks.

3 Conclusion

Catering to different communications environments and satisfying users' requirements for wideband, individualization and intelligence, heterogeneous network convergence has become the trend for next generation communications networks. The key technologies with QoS guarantee and communications capacity are the important subjects in the research of heterogeneous network convergence. The complexity of heterogeneous network resources, variety of network situations and differentiation of networks bring certain challenges to the research. However, challenges coexist with opportunities, and it is believable that heterogeneous network convergence technology will achieve success and become one of the mainstream technologies for future networks.

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