Next-Generation Converged Communication Protocol Stack System Postprint

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Abstract

In today' s continuously evolving heterogeneous networks, how to integrate different wireless access technologies to provide users with more diverse service forms and better quality of experience has become a pressing issue. This paper analyzes the air interface protocol stack system for next-generation converged communication networks from the access layer perspective, elaborates on the technical challenges in the design process, and proposes corresponding solutions. Finally, it proposes a protocol stack system architecture for next-generation converged communications.

Full Text

Preamble

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Abstract

With the continuous evolution of heterogeneous networks, integrating different wireless access technologies to provide users with more diverse service forms and better quality of experience has become an urgent problem to be solved. This paper analyzes the air interface protocol stack system in next-generation converged communication networks from the access perspective, elaborates on the technical challenges in the design process, and proposes corresponding solutions. Finally, it presents a protocol stack system architecture for next-generation converged communications.

Keywords: converged communication, heterogeneous networks, air interface, protocol stack

1 Background

As 3G network technologies are being commercialized globally, LTE technology continues to develop, and the post-3G era arrives, an increasing number of researchers and manufacturers have recognized that future wireless networks cannot be a single-technology, unified-management network composed of one particularly advanced wireless technology, as envisioned at the beginning of 3G research. Instead, they will inevitably be a union of heterogeneous networks formed by the convergence of multiple technologies and networks, featuring multiple access methods, providing multiple transmission rates, and supporting multiple services with diverse quality-of-service requirements.

In response to the characteristics of multiple access technology convergence in future heterogeneous networks, a large number of multi-mode terminal devices capable of simultaneously supporting multiple access technologies have entered the commercialization phase, such as multi-mode mobile phones, multi-mode PDAs, and multi-mode laptops. Additionally, NEMO (Network Mobility Support) has proposed wireless router devices for vehicles and vessels that can support multiple access technologies to meet the mobility and communication service quality requirements of large numbers of on-board users. Along with the development of wireless communication technologies and the increase in wireless transmission bandwidth, heterogeneous systems will support more diverse services compared to existing communication systems, and the service forms themselves are becoming increasingly complex. Real-time multimedia services such as voice and video are highly sensitive to delay and jitter, requiring higher quality of service, and often contain multiple data flows with different QoS parameters within a single application. These new characteristics of heterogeneous networks will greatly enrich people' s daily needs and promote the development of the wireless industry. However, existing general-purpose protocol stacks still cannot meet the requirements of seamless handover, real-time access, and service flow selection in heterogeneous wireless network environments. Therefore, researching how to truly leverage the characteristics of heterogeneous network convergence and multiple access technologies to provide users with more diverse service forms and better quality of experience is of great practical significance.

Future mobile communication networks will be trusted, guaranteed, all-IP heterogeneous converged networks with multiple coexisting and collaborative access technologies that support terminal mobility, possessing the capability for seamless handover and roaming across multiple wireless access technologies. This places higher demands on the next-generation convergence-oriented communication protocol stack. At each layer of the protocol stack, differences exist between heterogeneous access networks, and network convergence must resolve these differences at all layers. When multiple access networks coexist, a unified bearer protocol is needed to complete joint management of information sharing, terminal roaming, and wireless resource negotiation among various access networks, thereby enabling users to enjoy high-speed, high-quality, and high-stability services in heterogeneous network environments.

2 Overview of Next-Generation Converged Communication Networks

In today' s evolving heterogeneous networks, how to integrate different wireless access technologies to provide users with more diverse service forms and better quality of experience has become an urgent problem. Network convergence involves multiple layers of mobile communication systems, including the service layer, control layer, access layer, and transport layer.

At the service layer, new service forms such as mobile video, digital music, and mobile online gaming are emerging endlessly. In the future, the bottleneck that these diverse service forms cannot interoperate across different terminals will inevitably be broken, and entirely new digital entertainment models will develop more rapidly.

At the control layer, key technologies such as network-layer mobility management will provide seamless handover and roaming, changing the situation where different standard networks cannot hand over to each other. Users will be able to roam seamlessly between different networks (such as 2G/3G/4G) with their terminals. Through access-layer and non-access-layer control, user mobility and autonomous mobility management can be achieved.

At the access layer, joint radio resource management and quality-of-service guarantee technologies will provide smooth transition between services and achieve convergence of heterogeneous networks, enabling more effective utilization of various wireless network resources to provide high-bandwidth, high-quality services for users.

At the transport layer, key technologies such as IPv6 and next-generation Internet will guarantee transmission quality. Advanced wireless technologies enable users to enjoy video, music, Internet access, and other services while mobile. To access the Internet anytime and anywhere, each mobile terminal must be assigned an independent IP address. Traditional IPv4 far from meets the address capacity requirements, whereas IPv6 solves the address scale problem and brings significant improvements in security and quality of service, allowing the Internet to carry more services.

In terms of overall technology, various services can achieve interconnection based on IP. From the customer premises network to the access network and then to the core network, the entire network is unified through the TCP/IP protocol, enabling reliable connections among various terminals. IP services and their related standards, technologies, and infrastructure are already quite mature and widely popular. Therefore, converged mobile communication networks will use IP as the unified interface standard and connection means, becoming all-IP mobile communication networks.

Against this background, in converged communication networks, all network entities should run the same protocol stack. A next-generation communication protocol stack based on all-IP heterogeneous network convergence is the key to realizing products that provide converged communication capabilities. During the process of integrating different processing technologies, the protocol stack still faces many challenges, with numerous critical issues to be resolved. This paper will provide a detailed analysis of future converged communication network protocol stack systems from the access perspective.

3 Technical Challenges and Design Considerations

In the design and implementation of next-generation convergence-oriented communication protocol stack software systems, two major directions must be considered: first, the design and implementation of the protocol stack software itself; second, the design and implementation of protocol stack control-related algorithms, thereby maximizing the advantages of converged communication technology. The design tasks include:

3.1 High Data Transmission Rates

In response to users' continuously growing communication service scope and rate requirements, the proportion of data services in next-generation mobile communication systems (4G systems) will increase significantly. Service types may include various real-time or non-real-time services such as IP-PCM, VoIP, MPEG4, H.263, interactive gaming, Internet access, and email. Under the limited processing capability constraints of communication equipment, how to design the overall architecture of the protocol stack and how to effectively enable interaction among various functional modules while ensuring the software system is "highly cohesive and loosely coupled" to shorten data processing time are critical considerations during the software design phase.

The high-speed data processing and low-latency requirements of future communication systems demand higher standards for the engineering implementation of protocol stack systems, making it impossible to adopt the complex designs of traditional communication protocol stack software systems. Software system design should follow principles of simplicity, efficiency, and consistency. The functions of each protocol layer should be driven and controlled by state machines to effectively guarantee the timeliness and correctness of the entire system operation, and through effective interface design, maximize hardware capability utilization to ensure efficient operation and real-time performance of the entire protocol stack software system. During design, collaborative processing among protocol layers must be considered to improve system data processing efficiency. The following methods should be adopted:

3.1.1 Optimized Data Structures During processing across different protocol layers, information common to all layers (such as radio bearer and logical channel information in LTE) should be stored in core data structures, providing unified access interfaces to manage this information and reduce system data indexing time.

3.1.2 Streamlined Thread Model The strict requirements of future communication protocol stacks for data processing time (for example, LTE systems need to complete data scheduling within 1ms for the uplink) necessitate a certain degree of parallel execution among different protocol layers during data processing. However, thread switching during parallel processing increases system processing overhead. Therefore, during system design, a balance between these factors must be considered, and a streamlined thread model should be used to improve data processing efficiency.

3.1.3 Reduced Data Copying In engineering implementation, multiple copies of IP packets during processing across different protocol layers of the protocol stack will increase system processing overhead and data processing delay. Therefore, during IP packet processing across different protocol layers, pure pointer operations or other indexing methods can be employed to enable processing without copying or with only a single copy, thereby effectively reducing system processing overhead and minimizing data processing delay.

The comprehensive application of the above methods can optimize the overall air interface protocol processing, improve system response speed, and thus meet the high-performance data processing requirements of future higher-layer protocol stack software systems.

3.2 System Flexibility and Portability

With the rapid development of communication software technology, protocol stack software development is showing trends toward componentization and specialization. Different communication equipment manufacturers will conduct specialized division of labor based on different "concerns," developing different "components." Driven by different market demands and design concepts, they will select different protocol stack components, different real-time systems, and different hardware platforms to form various high-performance communication equipment through component assembly. How to design a flexible and easily portable protocol stack software system that reduces the dependency of higher-layer protocol stack software on operating systems, physical layer implementations, and hardware platforms, while ensuring system performance and reducing investment in system integration and upgrade processes, will become increasingly important in future communication equipment development. Based on in-depth analysis of existing communication protocol stacks (such as TD-SCDMA, WiMAX, 3GPP LTE, etc.), this paper addresses the flexibility and portability requirements of future converged communication protocol stack systems from the following aspects:

3.2.1 Core Database To achieve flexibility, communication protocol stack software needs to use a core database to store all important information from different protocol layers, including service management information, transmitted and received protocol data units, and statistical information. It serves as an important bridge for communication among various functional modules of the system. Additionally, we have established a flexible data organization method of "information sharing, multi-level indexing, and cross-access" on top of the core database. Under the premise of saving data only once, specific indexing methods are established according to different functional requirements, achieving fast and accurate indexing while saving embedded system storage space.

3.2.2 Dynamic Algorithm Library To facilitate the addition of new functions or replacement of core algorithms during system integration and development upgrades, and to enhance system flexibility and extensibility, a set of dynamic algorithm library interfaces and implementations must be defined. Through loose coupling, the system' s core algorithms and key mechanisms are encapsulated in dynamic algorithm libraries. During system upgrades, only the original implementation in the algorithm library needs to be redesigned and replaced according to the library interface to evaluate and verify the algorithm in the protocol stack software system, without requiring knowledge of other implementation details of the protocol stack.

3.2.3 Portability To improve the portability of protocol stack software systems, the scheduling subsystem, data transceiver subsystem, and other core parts of the protocol stack software can be made independent of specific operating systems, physical layer implementations, and hardware platforms through an operating system abstraction layer and a physical platform management subsystem. [Figure 2: see original paper]

Operating System Abstraction Layer: The operating system abstraction layer uses different operating system wrappers to shield operating system-specific data structures and function interfaces, enabling the core parts of the communication protocol stack to access operating system interfaces transparently. As long as the specific operations of the target operating system are encapsulated in the abstraction layer, higher-layer protocol stack software can be easily ported to that operating system. Meanwhile, the communication protocol stack can be optimized separately for different operating system characteristics to improve the performance of protocol stack software running on that operating system.

Physical Platform Management Subsystem: The physical platform management subsystem uses physical layer adapters to shield the details of underlying hardware platforms and physical layer implementations, enabling the core parts of higher-layer communication protocol stacks to transparently use the services provided by hardware platforms and physical layers. As long as the service interfaces of the target physical platform are encapsulated in this subsystem, higher-layer protocol stack software can be easily ported to that hardware platform or physical layer entity. Meanwhile, for different physical layer adapters, higher-layer protocol stacks can optimize data communication mechanisms, synchronization mechanisms, and primitive interactions based on hardware platform and physical layer characteristics, ensuring system portability while improving system data throughput.

3.3 Intelligent Radio Resource Management Algorithms

In any protocol stack system, radio resource management is a crucial component of the air interface protocol, directly affecting overall system performance and resource utilization efficiency. In converged mobile communication systems, due to the rapid increase in mobile users and their continuously growing communication service scope and rate requirements, the proportion of data services will increase significantly, placing higher data processing demands on protocol stack software. How to manage radio resources, better achieve the convergence of different communication access technologies, efficiently utilize limited communication resources, and on this basis guarantee multi-service quality of service and enhance user experience are the most important and critical research issues in converged communication protocol stacks.

In response to the growing number of mobile users and high-speed service demands, future communication protocol stacks need to provide higher spectrum efficiency and system capacity. Radio resource management algorithms in next-generation converged communication protocol stacks must be able to dynamically allocate spectrum resources, adjust system parameters, and coordinate resource allocation among different networks and among different cells within the same network based on current cell status, thereby providing optimal services for users under existing wireless resource conditions.

3.4 Green Wireless Communication Networks

In recent years, the growth gap between mobile Internet traffic and wireless air interface resources has become increasingly apparent. Data shows that the current annual compound growth rate of mobile Internet traffic is 131%, while that of air interface resources is only 55%. Consequently, the number of China Mobile base stations continues to grow, currently reaching 500,000. However, the negative effect is that power consumption has doubled within nearly five years, with electricity costs exceeding 10 billion RMB in 2009 alone. The information and communication technology industry has become a major energy consumer, accounting for 2%-6% of global energy consumption, and this proportion has been growing rapidly in recent years. Therefore, how to reduce power consumption has become a primary issue to be addressed in future communication protocol stack systems.

An important significance of converged communication is to provide greener communication services, achieve energy saving and emission reduction goals, reduce electromagnetic interference and radiation pollution, and simultaneously provide better wireless communication services and applications to ensure the sustainable development of the mobile communication industry. Compared with previous communication systems that focused on physical layer energy reduction technologies, in converged communication systems, adopting appropriate mechanisms to achieve maximum energy control while completing communication functions is a noteworthy issue.

4 Next-Generation Converged Communication Protocol Stack Architecture

In converged communication systems, the converged protocol stack software system needs to leverage the advantages of various wireless access technologies while accommodating heterogeneity, achieving collaborative configuration and efficient utilization of different network resources to support emerging modern service industry applications. The protocol stack system design adopts an open, layered architecture. Different protocol layers implement different functions, and different mobile communication devices can use different functional entities at the same protocol layer to perform different functions. [Figure 3: see original paper] shows the basic architecture of the converged communication protocol stack. To adapt to the high-speed data processing requirements of next-generation communications and the control diversity and complexity brought by the coexistence of multiple communication access technologies, the protocol stack design separates data processing functions from control functions. The entire layered architecture of the data processing function consists of the network communication capability layer, network communication driver layer, network layer, transport layer, and application layer from bottom to top. The protocol stack adopts a highly cohesive and loosely coupled modular design internally. Functions of the control plane need to use information from multiple layers to execute.

The network communication capability layer is the bottom layer of the converged protocol stack, reflecting the diversity of mobile devices' access capabilities to different communication networks. This layer integrates the physical layer, data link layer, and media access layer of multiple access technologies, providing better services for higher-layer data transmission and enabling mobile devices to access multiple communication networks. The network communication capability layer maintains the independence of different communication access technology operations to provide different service levels according to service requirements and provide load-balanced services according to network usage conditions.

The network communication driver layer serves as the communication interface between upper-layer protocols and lower-layer specific access technologies, providing point-to-multipoint data packet transmission. It is the most complex functional layer in the converged communication protocol stack. The network communication driver layer performs open, unified, standardized encapsulation of different underlying access technologies, providing a unified interface for upper layers and determining which communication method the upper network layer should use to send data based on the service provision capabilities of different networks.

Joint radio resource management is the information source for decision-making in the network communication driver layer. Future wireless networks will be a seamlessly converged heterogeneous system based on all-IP technology. In converged communication networks, the use of IP technology will bring significant statistical multiplexing gains to mobile communication systems while providing greater flexibility for system applications. All services will be transmitted on a unified platform, with quality-of-service characteristics being relatively dispersed, which greatly increases the complexity of radio resource management in 4G systems. Future mobile communication system radio resource management technologies require revolutionary changes:

- **Quality of Service Management:** Future converged communication networks need to support broadband integrated services with various quality-of-service requirements carried by interconnected heterogeneous networks. Quality-of-service management should achieve quality-of-service guarantees across different communication networks according to the different QoS requirements of different services.
- **Connection Management:** The heterogeneity of converged communication networks is mainly reflected in the differences in physical layer technology implementations among different communication network access technologies. Therefore, the function of connection management is to enable terminals to select appropriate access networks for communication based on mobile device service requirements and network conditions.
- **Mobility Management:** User mobility is a typical behavior in mobile communication networks. In heterogeneous network environments that integrate multiple wireless access capabilities, mobility management must guarantee service performance when users traverse networks based on different structures and protocols, providing users with ubiquitous network access services.
- **Resource Management:** In converged network environments, resources from different networks need to be coordinated and reasonably configured. Converged radio resource management will perform admission control, scheduling, interference suppression, load balancing, and other operations based on network resource usage conditions to achieve resource sharing and performance mutual benefits, ensure service transmission quality across multiple networks, and realize the harmonious coexistence and development of multiple communication technologies.

5 Conclusion

Converged communication is a new communication mode that integrates computer technology with multiple communication technologies into a unified networked platform to provide numerous application services. The development of multiple technologies has promoted the advancement of converged communication, among which software technology development enables various communication devices to support various user-required features, functions, and services through software changes.

In the era of converged communication, communication software plays a crucial role in the functional performance of communication equipment. Based on research status and technical analysis of converged communication, this paper proposes several key technical improvement points in software system development for the core software of converged communication systems—the converged communication protocol stack. It analyzes various aspects from software development to resource management and provides corresponding solutions and methods. Finally, it proposes an architecture for the converged communication protocol stack, enabling it to achieve unified and efficient communication services while accommodating heterogeneity, thereby saving costs and making full use of existing networks.

Converged communication represents an innovation in traditional communication, promoting diversified platform development and enabling rapid and convenient deployment of new technologies and applications, highlighting the advantages of a converged platform. In the highly competitive process of converged communication protocol stack and product development, there are various product development approaches. To promote the development of converged communication, standardized research on multi-platform and multi-terminal compatibility is needed according to the requirements of converged communication services for networks, terminals, and interfaces. This will achieve interoperability between different products and systems, provide a broader platform for converged communication, offer better solutions, and enable more rapid deployment and implementation of converged communication.

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Note: Figure translations are in progress. See original paper for figures.