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## Postprint of Cloud Base Station Technology in Wireless Communication Networks

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### Abstract

This paper analyzes the challenges confronting existing wireless communication networks in system architecture. It introduces a novel access network architecture—an access network based on cloud infrastructure—and analyzes the relevant key research contents. Subsequently, it describes the technical evolution path of this new architecture and feasible verification schemes.

### Full Text

## Cloud Base Station Technology in Wireless Communication Networks

**Huang Yi, Shi Jinglin**

### Abstract

This paper analyzes the challenges confronting existing wireless communication networks in system architecture, introduces a novel access network architecture based on cloud infrastructure, examines key research areas, and finally describes the technical evolution path and feasible verification solutions for this new architecture.

**Keywords:** Cloud Base Station, 4G Mobile Communication, Access Network, Air Interface

## 1 Overview

The wireless mobile communications industry currently faces an intensely competitive environment. On one hand, Average Revenue Per User (ARPU) growth has been sluggish, even declining year by year, impacting total revenue. Meanwhile, mobile internet traffic is rising rapidly, while expenditures for constructing, operating, and upgrading wireless access networks continue to increase,

severely weakening operator profitability. To maintain sustainable profits and long-term growth, operators must seek methods to provide wireless services at lower cost.

From a technical perspective, existing cellular networks suffer from serious problems. Traditional wireless access networks exhibit three key characteristics: (1) Each base station connects to a fixed number of sector antennas covering a small area, and can only process transceiver signals for its own cell; (2) System capacity is interference-limited, making it difficult to improve spectral efficiency with this independent base station operation mode; and (3) Base stations are typically proprietary platform-based “vertical solutions.”

These characteristics pose challenges for future mobile communications development. First, the enormous number of base stations entails high network deployment and construction costs. Second, actual resource utilization of existing base stations is low—network average load is generally far below busy-hour load, while processing capacity cannot be shared among different base stations, making spectral efficiency improvements difficult. Third, access network equipment based on multiple incompatible hardware platforms creates difficulties for capacity expansion or upgrades, yet network scaling is endless to meet growing mobile data service demands. Additionally, proprietary platforms complicate future heterogeneous wireless network deployment.

In summary, the high operation and maintenance costs, low resource utilization efficiency, and suboptimal system performance of traditional wireless access networks make the existing access network deployment model ill-suited for future wireless communication demands such as multi-network coexistence, high bandwidth, and wide-area coverage. Therefore, researching new wireless access network architectures is necessary to adapt to the new mobile internet environment and achieve high-performance, low-cost green wireless access.

Future wireless access networks must fully utilize multi-cell wireless resources, integrate interoperability requirements for multiple access technologies, and provide low-energy wireless mobile network access. They must satisfy the following requirements: reduce energy consumption, including both user terminal and core network energy; improve system spectral efficiency to support higher user bandwidth; and adopt open access network hardware platforms that support coexistence and implementation of multiple air interface standards on the same platform.

Under these circumstances, China’s mobile operators and manufacturers jointly proposed C-RAN (Cloud-RAN), a new wireless access network architecture. Centralized base station processing can significantly reduce the number of base stations needed to cover the same area, collaborative wireless remote modules and antennas can improve system spectral efficiency, while real-time cloud infrastructure and base station virtualization technologies based on open platforms can reduce costs, share processing resources, decrease energy consumption, and improve infrastructure utilization. In short, C-RAN’s characteristics

can effectively address the aforementioned problems. Of course, the goal of cloud base station technology is not to replace existing systems and standards, but rather to provide a low-cost, high-performance green network architecture from a long-term perspective. Its development still requires continuous technical research and exploration.

### **2.1 Reducing Wireless Access Network Energy Consumption**

Currently, to meet growing wireless broadband services and user numbers, the only approach is to continuously increase air interface bandwidth and base station quantities, making wireless access network energy consumption increasingly severe. Taking China Mobile as an example, over the past five years, its base station count has nearly doubled to provide better network coverage and capacity, while total power consumption has also nearly doubled. High energy consumption means significant environmental impact. According to EU estimates, by 2020, wireless communication carbon emissions will surpass those of traditional networks, making reduction of mobile communication network energy consumption urgent. Energy consumption in mobile communication networks primarily comes from wireless access network base stations. Therefore, the most direct and effective approach for energy conservation and emission reduction is reducing base station numbers. However, directly decreasing base station numbers under existing wireless access network architecture will inevitably lead to poorer network coverage and reduced capacity. Existing supplementary technologies such as software node solutions, intelligent shutdown technology, dynamic power control, and green energy usage are only auxiliary measures that cannot fundamentally solve the high energy consumption problem.

### **2.2 Implementing Heterogeneous Network Deployment**

Currently, 3G networks have gradually become popular worldwide, while existing 2G networks continue operating. Based on current market trends in users and wireless communication standards, 2G, 3G, B3G, and 4G networks will coexist long-term and gradually converge. In this context, multi-mode base stations represent an effective solution, with the key pathway to improving resource utilization efficiency being better hardware resource sharing within multi-mode base stations.

### **2.3 Improving Bandwidth and Spectral Efficiency**

With the introduction of B3G technology air interface standards, peak rates of wireless mobile communication systems are rapidly increasing, triggering rapid growth in end-user data traffic. In the coming years, as 3GPP LTE and LTE-Advanced are deployed globally, wireless communication bandwidth growth will prompt mobile users to consume more types of high-bandwidth multimedia services. It is estimated that from 2008 to 2013, global mobile data traffic will increase 66-fold, with an average annual compound growth rate of 131% [2]. Meanwhile, the peak rate of wireless air interfaces will only grow at an average

annual compound rate of 55%. This means access network bandwidth growth cannot meet data traffic growth demands. Therefore, high-capacity network access architectures and high spectral efficiency transmission schemes must be sought.

A fundamental characteristic of mobile networks is user mobility. During communication, users frequently move from one location to another. In fact, user movement exhibits strong temporal regularity: during daily work hours, large numbers of users move from residential areas to office districts, while the opposite occurs outside working hours. As these users move, network load exhibits a time-dependent migration phenomenon across the network—the “tidal effect.” In cellular networks, base station computing and wireless resources are tied to spatial locations. When cell load is low, base station resources are greatly wasted; meanwhile, when load is uneven, heavily loaded base stations cannot provide required processing capacity even when operating at full capacity. Therefore, achieving optimal wireless and computing resource allocation across the entire network is difficult.

Traditional wireless access network architecture appears helpless before these challenges, making the design of new access network architectures with novel concepts an urgent current need.

### 3 New Access Network Architecture—Cloud Base Station

To address these problems, operators, computer manufacturers, and academia jointly proposed Cloud Base Station (C-RAN) technology, integrating centralized processing, collaborative radio, and real-time cloud infrastructure. C-RAN mainly comprises three components: a distributed wireless network consisting of Remote Radio Units (RRU) and antennas; a high-bandwidth, low-latency optical transport network connecting RRUs; and a centralized baseband processing pool composed of high-performance general-purpose processors and real-time virtualization technology.

Remote radio module units provide a high-capacity, wide-coverage wireless network. Since these units are compact and lightweight, they are easy to install and maintain, enabling large-scale, wide-area, high-density deployment. The optical transport network features high bandwidth and low latency, capable of connecting all baseband processing units (BBU) and remote radio modules. The baseband pool is constructed from general-purpose high-performance processors connected through real-time virtualization technology to provide the processing capacity required by each virtual base station. The centralized baseband processing scheme enables resource aggregation and large-scale collaborative wireless transmission technologies, while real-time virtualization technology makes global optimization of physical resource utilization possible. Simultaneously, deploying C-RAN networks can easily achieve network coverage expansion and capacity increases. Open platforms and general-purpose processors also enable Software Defined Radio (SDR) technology to support multiple air interface stan-

dards or rapid upgrades to existing standards.

[Figure 1: see original paper]

Furthermore, the C-RAN architecture offers the following significant advantages:

- **Effective energy reduction:** First, centralized, virtualized base station solutions can greatly reduce equipment energy consumption. Second, the distance between remote radio modules and users decreases, allowing reduced wireless transmission power without affecting network capacity.
- **Increased network capacity:** In C-RAN, virtual base stations can share all communication users' reception and transmission signaling, service data, and channel quality information within the baseband pool. This enables multi-cell wireless resource joint allocation and scheduling, eliminates inter-cell interference, and even allows interference to be utilized, thereby significantly improving spectral efficiency.
- **Adaptive load coordination:** Networks can schedule wireless resources according to unbalanced loads across regions or time periods. Since the physical area served by the baseband pool is much larger than that of traditional base stations, the impact of large-scale load imbalance on resource utilization efficiency within the baseband pool can be overcome.

#### 4.1 Performance Analysis of Cloud Base Station Architecture

In mobile environments, the primary latency-sensitive component of data transmission is the air interface. Traditional air interface data processing and signal processing occur in base stations and mobile terminals, with fixed processing latency that has negligible impact on mobile transmission delay. However, in C-RAN, all information interaction in data processing and signal processing must occur between large base station processing pools and multiple remote radio modules at different distances and with different configurations, introducing various delays for different remote radio module units. Meanwhile, the entire system exhibits different transmission delay characteristics and overall system performance statistics across large scales compared to existing architectures. Therefore, on one hand, we need evaluation methods for these metrics to better guide optimal C-RAN system deployment and configuration; on the other hand, we also need fast calculation methods to obtain required reference values or feedback information to support flexible dynamic optimization using multiple key technologies.

#### 4.2 Cooperative Transmission and Wireless Resource Management Technology

Both 3G and 4G communication systems adopt Orthogonal Frequency Division Multiplexing (OFDM) technology as the physical means for signal transmission. However, in OFDM-based cellular networks, edge users experience severe Inter-Carrier Interference (ICI), degrading system performance. Since

system capacity is interference-limited, simply increasing base station transmission power cannot solve the problem. In the C-RAN architecture, system spectral efficiency can be effectively improved through joint resource allocation technology among multiple base stations and physical layer technologies such as Coordinated Multi-Point transmission.

Multi-cell wireless resource management has been extensively researched, aiming to maximize system throughput through optimization theory to design optimal resource scheduling and power control algorithms. When practically applied in C-RAN systems, time constraints for resource scheduling and data volume and network complexity for multi-cell information interaction must be comprehensively considered. Therefore, researching effective multi-base station cooperative scheduling and power control algorithms becomes critical.

### (1) Distributed Antennas and Cooperative Wireless Management

Currently, to improve overall system capacity, cellular networks in mobile computing environments have become increasingly dense, with shrinking distances between cells, resulting in higher frequency reuse factors and severe inter-base station wireless signal interference. In cloud base station systems, since remote radio modules are much smaller than traditional base stations, they can be deployed in more flexible and complex ways. One trend uses very small cell areas as the underlying network to achieve better spectral efficiency; another trend flexibly sets wireless nodes according to actual terrain and other factors to achieve optimized coverage performance, or uses distributed antennas to obtain local optimization performance among multiple antenna transmissions. Both approaches may introduce significant wireless interference and increase inter-cell cooperation complexity.

In the C-RAN architecture, since resources from multiple cells can be scheduled and managed cooperatively, cooperative signal transmission and reception technologies can be used to improve system spectral utilization and cell-edge user throughput. Cooperative transmission and reception technologies can be divided into two approaches: (1) **Joint Processing (JP)**: In this mode, data for multiple terminals is shared among multiple cooperative base stations, requiring significant system overhead; (2) **Coordinated Scheduling**: Multiple cells cooperatively determine their respective scheduling results to reduce interference. This mode can improve cell-edge user throughput with relatively small overhead through cooperative beamforming.

### (2) Wireless Resource Allocation Algorithms in Cloud Computing Environments

The C-RAN architecture completely overturns the foundation of traditional wireless resource management, replacing cell-level wireless resource management based on individual basebands with large-scale centralized wireless resource control mechanisms. This makes traditional wireless resource management techniques unsuitable for direct application to C-RAN systems. Wireless resource management under the base station processing pool approach may bring signif-

icant system improvements because virtualization pool technology breaks the physical barriers for information interaction and cooperation between base stations, allowing wireless resource management algorithms to optimize calculations and allocations with the entire system as the solution space to better approach system-wide performance limits. Meanwhile, the cloud computing environment provides sufficient computing capacity to achieve load balancing among cells on fine-grained time scales. However, research on high-performance wireless resource management algorithms remains necessary to improve wireless resource allocation efficiency while ensuring low energy consumption, thereby breaking through the bottleneck of spectral efficiency improvement.

### 4.3 Base Station Virtualization Technology

Currently, base station functions are implemented using dedicated baseband processing units. These units are designed for specific communication standards and support only a fixed number of carriers. Computing resources on baseband processing units are dedicated exclusively to physical layer or MAC layer processing. This design creates several problems: (1) Fixed hardware design cannot satisfy dynamic changes in different traffic and configuration scenarios, leading to low hardware resource utilization; (2) Dedicated hardware design makes it difficult to implement multiple air interface standards simultaneously; and (3) Fixed hardware design cannot adapt to the computational demands of new technologies.

To address these problems, one solution is to introduce widely used virtualization technology to abstract hardware resources of dedicated base station equipment, thereby presenting a more general computing platform. This resolves problems caused by dedicated, fixed hardware design and system architecture. After virtualization, base station equipment sets are transformed into virtualization pools with real-time baseband processing capabilities. Functions traditionally performed by individual base stations—physical layer, MAC layer, hardware acceleration, and control—are all implemented in the unified baseband pool. This enables rapid implementation of multiple air interface standards in the base station pool and facilitates convenient upgrades and maintenance of existing interfaces.

Communication access networks feature large scale and strong real-time requirements, so the baseband pool cannot completely copy existing virtualization computing platform technologies. The following issues must still be resolved: (1) Achieve efficient virtualization platforms with dynamic allocation of physical resources to virtual base stations, ensuring real-time performance, processing delay performance, and controllability of virtual base stations; (2) Design virtualization platforms that support multiple air interface standards and enable rapid deployment of new technologies; and (3) Develop resource scheduling algorithms for virtualization platforms to optimize resource allocation and improve system performance.

### 5.1 C-RAN Architecture Evolution Roadmap

As a large-scale architectural innovation, cloud base station technology cannot be achieved overnight. Its various technologies require repeated testing and verification in experimental environments to ensure reliability. A feasible gradual evolution roadmap is as follows:

1. **Resource scheduling at the carrier level among multiple baseband processing units within centralized base stations.** Centralized base station pools contain both a high-capacity, low-latency switching matrix and relevant protocols supporting interconnection among multiple baseband processing units. This enables centralized base stations to effectively achieve carrier load balancing, improve equipment utilization, and reduce energy consumption.
2. **Complete implementation of baseband processing unit functions using general-processor-based software radio.** By connecting multiple remote radio modules to centralized baseband processing units and implementing software radio within them, cooperative signal processing becomes easier to achieve. Cooperative processing can maximize system capacity and reduce system interference.
3. **Finally, connect large numbers of general-purpose processors through high-bandwidth, low-latency interconnect architecture to form a massive real-time cloud computing virtual baseband pool.** The main differences between this baseband pool and widely used cloud computing systems in the IT industry are its specialization and real-time capability. Real-time cloud computing forms a virtual base station pool composed of multiple virtual base stations, with each virtual base station obtaining computing resources through dynamic allocation from the baseband pool to complete real-time processing of wireless baseband signals.

### 5.2 Verification and Application of Cloud Base Station Technology

During the aforementioned technology research period, to enable performance analysis and verification in relatively realistic environments, a cloud base station experimental platform can be built on general-processor-based software radio platforms. Currently, the Sora software radio solution proposed by Microsoft [3] is a relatively high-performance software radio platform. Therefore, the Sora platform can be selected to build the experimental system, with its structure shown below:

[Figure 2: see original paper]

The above software radio platform uses X86-based general processors as baseband processing and data processing units, connecting to RF antennas through Radio Control Boards (RCB). This hardware connection approach is similar to cloud base stations. Each software radio set can be viewed as a combination of

RF/antenna endpoints and base stations. General processor systems are connected through wired connections to form information networks, and deploying cloud computing software systems on them can create a cloud base station simulation environment. On this platform, air interface links such as LTE can be implemented through software programming methods to construct a cloud base station technology experimental platform.

## 6 Conclusion

The wireless access network is a critical component and primary hallmark of wireless communication systems, yet its fundamental architecture has remained largely unchanged. As the world moves toward the 4G era, the existing access network system can no longer satisfy future wireless communication demands regarding system energy consumption, transmission capacity, and low-cost operation and maintenance. This paper analyzes the major challenges facing existing wireless access networks, describes the novel C-RAN system, and analyzes its key research topics requiring breakthroughs. Based on this analysis, we present a phased evolution roadmap for C-RAN technology and propose a software radio approach for building a small-scale experimental environment for C-RAN technology verification.

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## Advanced Wireless Cooperative Communication Technology

Using wireless cellular network systems as an example, this article introduces advanced wireless cooperative communication technology primarily from the perspectives of cooperation among base stations, cooperation between base stations

and terminals, cooperation among terminals, and cooperation among heterogeneous networks.

Evidently, the contradiction between the continuous demand for physical layer link performance improvement and the severe shortage of wireless resources has become a bottleneck for future wireless system development. Conflicts between system capacity and user fairness, along with inter-cell interference, have become major obstacles restricting further wireless network development. Extensive cooperation among different network elements and sufficient cooperation among heterogeneous networks to improve air interface spectral efficiency and overall system performance will inevitably become one of the most effective means to solve these problems and an important pathway to achieving green wireless communication networks.

Currently, cooperative communication research remains an open issue, with ongoing discussions in standards development and many research topics underway. What impact will cooperative communication technology development have on various aspects of wireless networks, particularly LTE-A? How should we face the challenges and opportunities brought by new-generation wireless communication technologies? These questions require further exploration by academia and industry peers.

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