Cloud Radio Access Network (C-RAN): A Primer

Jun Wu, Zhifeng Zhang, Yu Hong, and Yonggang Wen

Abstract

In the era of mobile Internet, mobile operators are facing pressure on ever-increasing capital expenditures and operating expenses with much less growth of income. Cloud Radio Access Network (C-RAN) is expected to be a candidate of next generation access network techniques that can solve operators' puzzle. In this article, on the basis of a general survey of C-RAN, we present a novel logical structure of C-RAN that consists of a physical plane, a control plane, and a service plane. Compared to traditional architecture, the proposed C-RAN architecture emphasizes the notion of service cloud, service-oriented resource scheduling and management, thus it facilitates the utilization of new communication and computer techniques. With the extensive computation resource offered by the cloud platform, a coordinated user scheduling algorithm and parallel optimum precoding scheme are proposed, which can achieve better performance. The proposed scheme opens another door to design new algorithms matching well with C-RAN architecture, instead of only migrating existing algorithms from traditional architecture to C-RAN.

Nowadays mobile operators are facing a serious situation. With the introduction of various air-interface standards and the prevalence of smart devices, mobile Internet traffic is surging, and operators are forced to increase capital expenditure (CAPEX) and operating expense (OPEX) in order to meet users' requirements. On the other hand the average revenue per user (ARPU) cannot catch up with the increasing expenses. It is predicted that the traffic will double every year in the next decade from 2011 to 2020 [1], which will require more cost to build, operate, and upgrade the network infrastructure, while only a small increase on the revenue is expected. The operators have to find new solutions to maintain a healthy profit and provide better services for customers.

To cater to the increasing traffic requirements in an energy-efficient way, there are several alternatives. The first option is to improve the spectrum efficiency by employing more advanced transmission techniques such as MIMO and beamforming, which have a theoretic limit. There has been significant progress in recent decades, but now we are approaching the limit. The second option is to exploit spectrum holes through dynamic spectrum access technologies such as cognitive radio, but it cannot ensure consistent and reliable services, and the growth of data capacity is also limited. The third option is to deploy more cells with smaller size and take full advantage of frequency reuse, which will introduce more interference and increase the cost of infrastructure operation and management.

Energy efficiency is also very important from the perspective of reducing operating cost and carbon dioxide emission. As statistics from China Mobile shows, the majority of power consumption is from base stations (BS) in the radio access networks (RAN), but BS power efficiency is only 50 percent [2]. Increasing cell sites will cause more power consumption, resulting in higher OPEX and a negative impact on the environment. Smaller cells with more aggressive frequency reuse will lead to more frequent cell handoffs for mobile devices [3].

Due to the dramatic increase in population density in both residential and business areas, network load in mobile network also changes in a time-geometry pattern called the "Tidal Effect." Unfortunately, in current RAN architecture the processing capacity of a BS can only be used for its own mobile users instead of being shared in a large geographical area. Thus during the day BSs in business areas are over-subscribed while BSs in residential areas stay idle while still consuming a large amount of power, and vice versa. It becomes a pressing need to improve existing RAN architecture to better solve this problem and free up the capacity of these technologies.

Nowadays multi-core processors are becoming increasingly powerful, and the cloud computing-based open IT platform is a promising alternative for both IT service providers and mobile operators.It is time for mobile operators to consider using the cloud computing facility to form a much larger processing resource pool shared in a large geographical area to achieve low-cost operation. The new RAN should meet the following requirements:

- Support of multiple air interface standards and flexible software upgrade.
- Provision of reliable services with reduced cost, while maintaining healthy revenue.
- Optimization among capacity, mobility, and coverage in broadband cellular wireless systems.

Cloud Radio Access Network (C-RAN) is a new paradigm

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proposed by a few operators that features centralized processing, collaborative radio, real-time cloud computing, and power efficient infrastructure. This novel architecture aggregates all BS computational resources into a central pool; the radio frequency signals from geographically distributed antennas are collected by remote radio heads (RRHs) and transmitted to the cloud platform through an optical transmission network (OTN). It aims to reduce the number of cell sites while maintaining similar coverage, and reducing capital expenditures and operating expenses while offering better services.

Up to now many well-established companies are engaged in the C-RAN project, such as IBM, Intel, Huawei, and ZTE. However, recent research focuses on the architecture of the underlying layer with special processors; very few proposals related to the service layer of C-RAN have been presented. Only [4] proposed a novel concept of cognitive wireless cloud and its service. Our article covers the notion of service layer and gives a new logical structure of C-RAN.

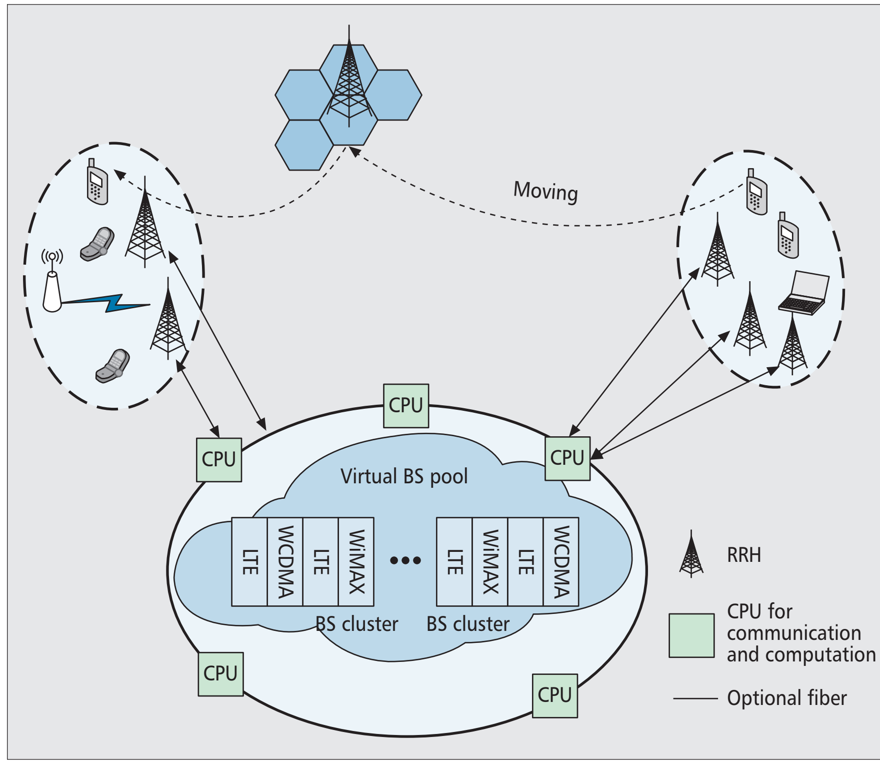

Figure 1. C-RAN infrastructure with multi-mode support.

Spectrum utilization, power consumption, and the cost of building, operating, and managing RAN are three major topics that operators care about in wireless networks. Multicell cooperation processing can significantly improve spectrum efficiency and reduce power consumption. Current research mainly considers multicell cooperation based on traditional BS architecture [5–7], which is limited by BS interconnection, BS processing capability, and the backhaul network. C-RAN is characterized by high-speed interconnection and shared powerful processing capability, thus facilitating optimal multicell cooperation processing [8]. With the new C-RAN architecture, some advanced algorithms can be implemented in parallel.

This article presents a definition, function, and current research challenges of C-RAN. In the following section we provide a brief overview of the infrastructure of C-RAN. Then we present the logic structure of C-RAN that can be implemented in the cellular broadband wireless systems. Then we present multicell cooperation processing in traditional BS architecture. We then present a coordinated user scheduling algorithm and parallel optimum precoding that are specifically designed for C-RAN, followed by performance evaluations. Finally, we conclude the article.

Cloud Radio Access Network Architecture

C-RAN is designed to be applicable to most typical RAN scenarios, from macro cell to femtocell. As shown in Fig. 1, it is composed of the baseband unit (BBU), optical transmission network (OTN), and remote radio head (RRH). The BBU acts as a digital unit implementing the base station functionality from baseband processing to packet processing, while the RRHs perform radio functions, including frequency conversion, amplification, and A/D and D/A conversion. The RRHs send/receive digitalized signals to/from the BBU pool via optical fiber, and antennas are equipped with RRHs to transmit/receive radio frequency (RF) signals. By placing numerous BBUs in a central physical pool while distributing RRHs according to RF strategies, operators can dynamically employ a real-time virtualization technology that maps radio signals from/to one RRH to any BBU processing entity in the pool. The benefits of C-RAN lie in the following four areas.

Reduced Cost: C-RAN aggregates computation resources in a few big rooms and leaves simpler functions in RRHs, thus saving a lot of operation and management cost. C-RAN makes equipments more effectively shared, such as GPS and transmission devices, thus reducing capital expenditure. Load balancing and scalability can be well achieved through virtualization, thus reducing waste of resources.

Better Energy Efficiency: C-RAN frees up individual BSs from the commitment of providing 24/7 services. All processing functionalities are implemented in a remote data-center. Power consumption and load congestion can be reduced by dynamically allocating processing capability and migrating tasks in the BS pool, and several BSs can be turned to low power or even be shut down selectively. Operators only need to install new RRHs connecting with the BBU pool to cover more service areas or split the cell for higher capacity.

Improved Spectrum Utilization: C-RAN enables sharing of channel state information of each base station-mobile station (BS-MS) link, traffic data, and control information of mobile services among cooperating BSs. This promotes the schemes of multi-point cooperation, and enables multiplexing more streams on the same channel with little or even no mutual interference, thus increasing system capacity.

Business Model Transformation: The cloud concept will generate more business models, such as the BS pool resource-rental system, cellular infrastructure and intellectual property agency, and more freemium services. Examples can be found in [4]and [9].

Srvice Cloud Logic Structure

Current wireless access networks are gradually evolving from a hierarchical structure to a flattened one. With the centralized nodes such as the base station controller (BSC) and the

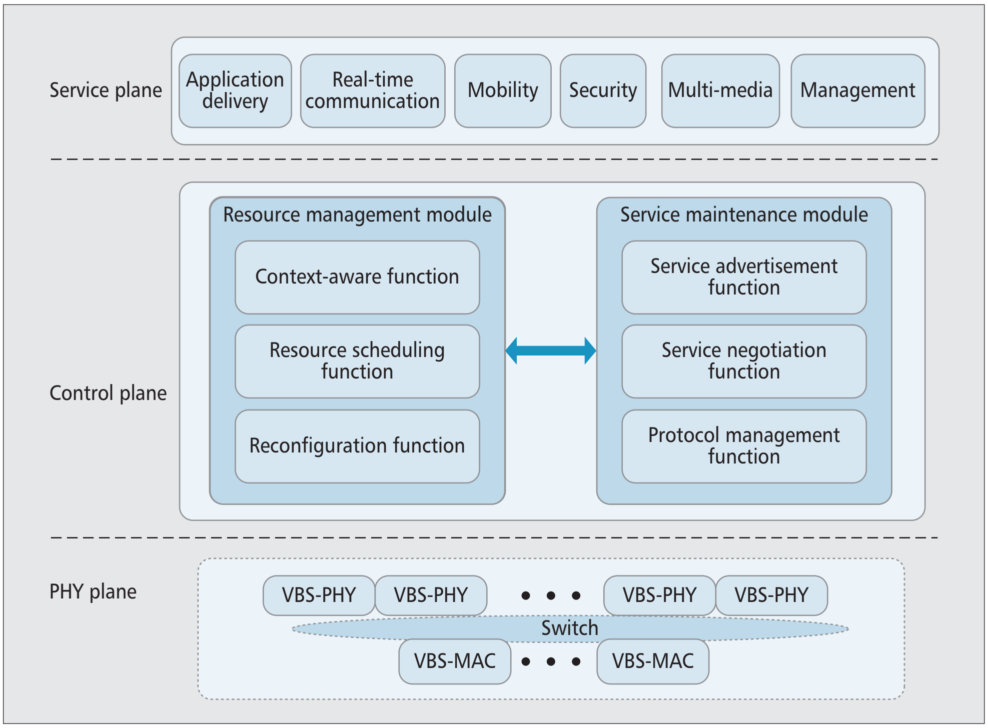

Figure 2. C-RAN logical structure with physical, control and service plane.

radio network controller (RNC) removed from the LTE network, the flattened architecture is more suitable for the cloud. On the other hand, an increasing number of mobile devices are capable of supporting multiple access technologies and more functions, which require better services from the BS side. The concept of cognitive wireless cloud (CWC) has been proposed in [4, 10–12]. With cognitive radio (CR)technology, opportunistic capacity extension in congested wireless networks and broadened coverage of infrastructure are achieved, but no service layer is involved in the above references. In this section we focus on service-oriented architecture design, and propose a kind of service cloud managing content, commerce, service provision, and subscribers. We aim to serve both terminals and operators with better network performance. The proposed logical structure is shown in Fig. 2, which consists of three planes: physical, control, and service.

Physical Plane

Based on the recent developments in cloud computing and software defined radio (SDR) techniques, C-RAN is able to use general-purpose processors (GPPs) with multicore and multithread techniques to implement virtualized and centralized baseband and protocol processing, such as PHY and media access control (MAC) layers [9].

In order to reduce power consumption and improve processing capability, hardware accelerators are preferred for computation-intensive tasks even in C-RAN, e.g. Turbo decoders, FFT, and MIMO decoders. In order to use these hardware accelerators efficiently and flexibly in the C-RAN environment, challenging problems need to be addressed. One is a high-throughput interface to facilitate data exchange between the cloud platform and the accelerators pool. The PCIe interface is a good candidate. The other is the I/O virtualization technique that enables hardware accelerators to be flexibly shared by the cloud platform. I/O virtualization can be further categorized into software-based and hardware-assisted techniques. In order to meet C-RAN's stringent requirements, I/O virtualization is generally implemented in hardware-assisted techniques. The virtualized hardware accelerators are a special kind of computation resource. The PHY plane mainly deals with the following three tasks.

Virtualization for Resource Provisioning: In the virtual BS pool, any BS instances can be served by more than one GPP node and accelerator; the PHY and MAC layer of the same BS instance can run on different GPP nodes. New BSs can be added and any existing BS can quit very easily via virtualization techniques. Because the traditional bond between cellular infrastructure and corresponding software/hardware authorization is weakened, cellular operators can flexibly select optimal cellular software/hardware according to changing needs.

Baseband Pool Interconnection: In order to facilitate dynamical scheduling of computation and accelerator resources for virtual BSs, some efficient topology schemes for interconnections are needed among CPUs in the same BS, BSs in the same rack, and among different racks. The interconnections are supposed to be high-bandwidth, low-latency, and low-cost.

Signal Processing: The whole RAN is supposed to be implemented in a data center, which is mainly comprised of GPPs and accelerators. After receiving signals from the optical transmission network (OTN), the GPPs and accelerators coordinate to perform signal processing tasks such as channel decoding, demultiplexing, and Fast Fourier Transform (FFT).

Control Plane

This plane implements functionalities based on the underlying physical plane, and supports the service plane. It enables user-centric RAN reconfiguration and RAN selection that are situation-aware and application-aware. This plane mainly contains two modules: the resource management module (RMM) and the service maintenance module (SMM).

Resource Management Module — This module takes charge of available radio resources and computation resources, from both network and terminal perspectives, to realize high QoS, seamless mobility, and power utilization efficiency. It is comprised of three functions: the context-aware function (CAF), the resource scheduling function (RSF), and the reconfiguration function (RF).

Context-Aware Function: This function collects context information on terminal and network aspect and forwards it to the RSF. The terminal-related context information includes users' service preferences, QoS requirements, battery consumption, channel state information (CSI) of its accessible multi-links to the BSs and other terminals, location, and movement of terminals. The network-related context information is a collection of availability of radio access technologies (RATs), the QoS of available networks, privacy and security issues, as well as cost requirements of operators.

Resource Scheduling Function: Given the context information, the RSF anticipates the possible RANs for terminals according to its network criteria model, including network objectives and terminal preference. Then, based on the feedback of negotiation results from the service maintenance module, the RSF makes the ultimate context scheduling decisions and delivers the outcomes to RF.

Reconfiguration Function: On one hand, the RF communicates with RSF periodically to obtain reconfiguration decisions and execute them punctually for RANs and terminals. On the other hand, the RF records the decisions in an updated global list for reference.

Service Maintenance Module — This module takes charge of available services from the perspective of the network, as well as negotiation and realization of services between network providers and terminal consumers. It is comprised of three functions: the service advertisement function (SAF), the service negotiation function (SNF), and the protocol management function(PMF).

Service Advertisement Function: There are two types of service advertisement: centralized and distributed. In the centralized service advertisement, a service node masters a global list of service information from other nodes and advertises it to terminals. In distributed service advertisement, all service nodes are equal to advertise services to terminals. Given the recommended RAN strategies from the RSF, the SAF will generate a virtual map of the RAN landscape and broadcast or unicast it to potential terminals that are or will be in the coverage area of those RANs.

Service Negotiation Function: This function takes charge of the price-and-service evaluation mechanism. It offers predicted QoS levels and the cost of each network connection from the operator and terminal perspectives. Then the terminal and operator reach an agreement on the primary connection and assistant connections for each terminal, and feedback the outcomes to the RSF.

Protocol Management Function: This function implements interfaces among the MAC, the service protocol, the wireless application protocol, and the routing protocol. Also, some issues such as privacy, security, and authentication are processed in this function.

Service Plane

The service plane is a platform where fixed and mobile services are provided and managed by telecommunication and IT players. Subscribers obtain services from the cloud as if it is a black box, while each service can be supported by multiple RATs simultaneously. This plane comprises a scalable library of network-based services to deliver voice, data, and multimedia applications in a consistent, robust, and efficient manner. The typical services are listed as follows:

- **Application delivery service:** The service plane provides the specific functionality to enhance the delivery of applications in aspects of application values, application transport protocol, application availability, and acceleration, using performance metrics such as cost-efficiency, load balancing and scalability.
- **Communication service:** The service plane offers more fluent text messages and audio and video sessions.
- **Mobility service:** The service plane provides seamless and transparent handoff to mobile UEs.
- **Multimedia service:** The service plane enables video streaming to cover entertainment, education, journalism, and industry. One of the cutting-edge technologies is the multiscreen experience, which engages multiple UEs in screen interaction whenever and wherever through the Internet.
- **Management service:** The service plane provides remote monitoring and operations at the industrial level.
- **Security service:** The service plane protects the infrastructure and data from invasion, and provides identity recognition and access control.

C-RAN Joint Resource Management

Broadband cellular wireless systems present great challenges to operators. On one hand they need to achieve reduced cost, high spectrum utilization, and low power consumption for operators; on the other they need to provide smooth mobility and high data rate for end users. We first review multi-cell cooperation processing in a traditional architecture, and then we propose a coordinated user scheduling algorithm and a parallel optimum precoding scheme, which can make use of the computation resources provided by the C-RAN architecture to futher improve system capacity.

Multi-Cell Cooperation Processing in a Traditional Architecture

As inter-cell interference (ICI) can significantly deteriorate the cell-edge user's performance, thus cause a decrease in cell capacity, multi-cell cooperation processing (MCP) is widely accepted to be a feasible way of reducing ICI and improving system capacity. MCP achieves obvious gains at the cost of increased signaling and infrastructure overhead [5]. As a typical MCP technique, coordinated multipoint transmission (CoMP) has to acquire both CSI and user data, thus requiring high-capacity and limited-delay backhaul links.

In order to reduce feedback from users and signaling/data overhead from inter-base information exchange, a feasible strategy is to restrict the cooperation within a limited number of base stations, which are called a cluster of BSs. On the terminal side, how many users and which users are multiplexed on the same radio resources are the next problems to be addressed, which are called user pairing. After both BSs and terminals involved in cooperation are determined, precoding and power allocation are performed to calculate weighting coefficients for antennas distributed in multiple BSs.

We consider a cluster of K base stations (BSs) where each BS has N_t transmit antennas. There are M single-antenna users in this cluster, so the received signal at BSs is represented as

$$y = HW\sqrt{P}x + n,$$

where H is the complex channel coefficient matrix from K BSs to M users, W is the complex precoding matrix for K BSs, P is the power allocation matrix, x is the signal for M users, and $n \sim \mathcal{CN}(0, \mathrm{I})$ is an i.i.d. Gaussian noise vector.

Precoding is intended to weight and combine transmit signals from all cooperative BS antennas for user pairs. Three classic linear precoding techniques for MCP are: matched filtering (MF), zero-forcing (ZF), and Wiener precoding. MF weights the signal from each antenna to make them combine constructively. The MF precoding matrix W is a conjugation

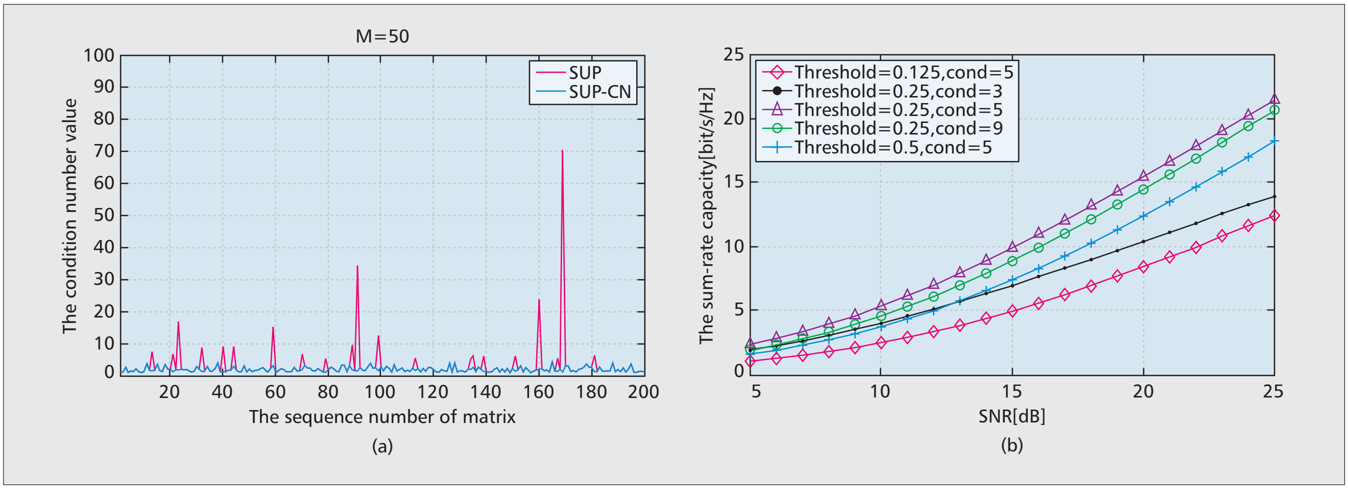

Figure 3. The comparison between SUP and SUP-CN. a) The condition number of selected users' channel matrix for SUP and SUP-CN; b) The sum rate of SUP-CN algorithm with different parameters.

of the intended users' channel matrix, thus MF maximizes SNR. The ZF precoding matrix W is designed to be orthogonal to the subspace formed by interference users, so that interference to other users are minimized. Wiener filtering tries to achieve balance between signal power maximization and interference power minimization, which maximizes the signal to interference and noise ratio (SINR).

MF, ZF, and Wiener select the beamforming direction W, while the power allocation P determines the signal strength along each direction. In CoMP working mode, each coordinated transmission point has a transmission power constraint, and multiple transmission points coordinately allocate power to transmit antennas to maximize system capacity. The optimal power allocation has been proven to be water filling [12] across multiple BSs.

Parallel Multi-Cell Cooperation Processing in C-RAN

Different from conventional RAN, C-RAN enjoys great advantages from the virtual BS (VBS) pool, enabling both coarse-grained and fine-grained cooperation [3]. We perform multi-cell cooperation with the selected users using similar service types. The multi-cell cooperation includes cluster formation, user pairing, and precoding. We use static and network-centric cluster formation, which divides the network into a set of disjoint clusters of base stations based on geographical distance, with one base station belonging to one cluster. We propose a condition number-based user pairing algorithm and a parallel implementation for optimum linear precoding.

Semi-Orthogonal User Pairing Based on Condition Number (SUP-CN) — The paired users should be in good radio channel conditions and also be sufficiently separated in space to minimize multi-user interference. The CQI is exploited to select a subset of users that experience good channel conditions in terms of SINR, so that it is worthwhile to perform multi-user MIMO transmission for them. Therefore the first step is to select the users corresponding to the CQI value above a certain threshold as a candidate user subset.

The second step is to select users from the candidate user subset based on channel correlation: the users with less correlated channel vector are better to be multiplexed on the same time frequency resource; the orthogonal users are best for pairing. Here we employ the cosine of the angle q between two channel vectors to measure the orthogonality between two users. Namely, if $\cos\theta = 0$, then $\theta = 90°$ or $270°$, which means two vectors are orthogonal. When $|\cos\theta| \le \varepsilon$, one of the vectors deviates a certain angle from the orthogonal position, which is determined by the threshold ε. This is the so-called Semi-orthogonal User Pairing (SUP) algorithm.

It is obvious that the traditional SUP algorithm doesn't perform well under the circumstance that the selected users are not really well orthogonal. So we propose to use condition number as an additional filter to pick up users with better orthogonality. The new algorithm combines the SUP and the condition number to improve the orthogonality of the selected channel matrix. Thus it is abbreviated as the SUP-CN algorithm.

The condition number is an important quantity in numerical analysis, which impacts the accuracy of solutions for a linear equation. In general, the condition number can be defined as:

$$\kappa(H) = \|H^{-1}\| \cdot \|H\|,$$

where $\|\cdot\|$ denotes the certain kind of matrix norm. We can see that $\kappa(H)$ measures the bound of the inaccuracy of the solution of the linear equation. The condition number meets $\kappa(H) \ge 1$. When $\kappa(H) = 1$, the matrix H is a well-conditioned and unitary matrix. While the condition number is large, the matrix is ill-conditioned and may cause errors in solutions to a linear equation. Depending on different types of norm, the condition number also has different forms. Here we define the $\|\cdot\|$ as the ℓ^2 norm, then the corresponding condition number is simplified as the ratio of maximal and minimal singular values of matrix H.

Here we set a threshold of the maximum condition number value that guarantees a good orthogonality of matrix H. If the condition number of channel matrix H with a new user is smaller than that threshold, then the new user is added. Otherwise, the user selection process continues.

Parallel Optimum Linear Precoding — For each candidate user pair, we consider the sum rate as an objection function to optimize precoding matrix W. This optimization problem has been formulated in [8] as

$$\max_{w_m} \quad \sum_m \log\left(1 + \frac{\left|h_m^H w_m\right|^2}{\sigma_m^2 + \sum_{i \ne m}\left|h_m^H w_i\right|^2}\right) \forall m \in M$$

$$\text{s.t.} \quad \sum_{l=1}^{L_k} w_l^H P_{lk} w_l \le p_k \quad \forall k \in K,$$

where w_m and h_m are the precoding weight and channel for the m-th user, respectively, σ_m^2 is the noise variance, L_k is the number of users that belong to BS k, P_{lk} is the covariance

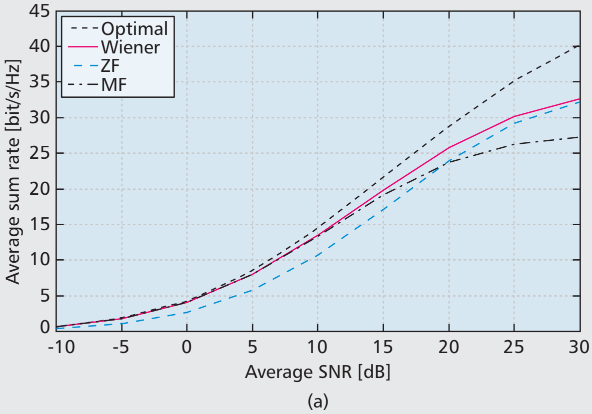

Figure 4. Downlink average sum rate, cluster consists of 7 cells and each BS is quipped with 4 antennas. a) 7 cells and 4 antennas/cell form a cluster,7 users are paired. b) 7 cells and 4 antennas/cell form a cluster,14 users are paired.

matrix of transmitted signals, p_k is the power constraint for BS k. This optimization problem is generally a non-convex, but a monotonic problem. The Branch and Bounding (B&B) algorithm could be used to solve this problem, as its computational complexity scales exponentially with the number of users.

C-RAN encapsulates the network elements on a general-purpose server as a virtual machine(VM). The processing capacities of all participating BSs are aggregated together and can be scheduled by a central node. With the parallel computation capability provided by C-RAN, we propose to implement a parallel B&B algorithm. B&B is based on enumeration of all candidate solutions and pruning of large subsets of candidate solutions via computation of lower and upper bounds. At each step of the B&B method, we expand the selected best subproblem into multiple subproblems, then process them in parallel. The central node will collect the computation results and find the best subproblem.

Performance Evaluation

In this section we evaluate the performance for the SUP-CN and the parallel optimum precoding algorithms, respectively. For SUP-CN, a MIMO system with a base station of $N_t = 4$ antennas and $M = 50$ users with a single antenna is considered.

In Fig. 3a the condition numbers of traditional SUP are plotted, which are usually larger than that of SUP-CN. We know that a large condition number means a poor orthogonality. The SUP algorithm just ensures the quasi-orthogonality between two channel vectors, but the condition number can guarantee the quasi-orthoganality among all selected users by evaluating the condition number of their channel matrix, thus SUP-CN is expected to be better than SUP.

We compare the sum-rate of SUP-CN with orthogonality threshold $\varepsilon = 0.125, 0.25, 0.5$ along with condition number threshold $cond = 3, 5, 9$, respectively, as shown in Fig. 3b. It is obvious that SUP with threshold $\varepsilon = 0.25$ has the best performance among three parameters. The threshold $\varepsilon = 0.125$ means better orthogonality, but it is hard to select users who meet this strict requirement. The threshold $\varepsilon = 0.5$ is too relaxed such that the two vectors are not well orthogonal. The SUP-CN algorithm introduces an additional filter into the SUP, which discards the users leading to a big condition number value and reserves the good users. We observe that the performance of $cond = 5$ is the best among the three different condition numbers for a common SUP threshold $\varepsilon = 0.25$. The smaller *cond* means better orthogonality, but it is harder to pick up appropriate users. Therefore, the selection of both thresholds is a trade-off between orthogonality and the difficulty of selection.

We evaluate the performance of MF, ZF, Wiener, and parallel optimum precoding with seven neighboring cells, 50 users are randomly distributed in each cell, and each BS is equiped with four antennas. A free-space propagation loss model $20\log_{10}(d) + 20\log_{10}(f) + 32.45$ dB is used, where d and f are in kilometer and megahertz, respectively. The cell radius is set to 1000 meters. An uncorrelated Rayleigh fading channel model is used for small-scale fading. The SUP-CN algorithm with threshold $\varepsilon = 0.25$ and $cond = 5$ is used for user pairing.

We simulate two scenarios. In one scenario seven BSs are coordinated to serve seven users who belong to seven different cells, respectively. In the other scenaro seven BSs are coordinated to serve 14 users who belong to seven different cells, with each cell having two active users. Each BS is equipped with four antennas. The performances for both simulation scenarios are shown in Fig. 4a and b, respectively. When the number of users increases from seven to 14, the inter-cell interference (ICI) deteriorates and the freedom of MIMO decreases, thus the spectrum efficiency of optimum liner precoding increases only a little from 45 to 50 bits/s/Hz. The advantage of optimum precoding over Wiener and Wiener over MF is expanded with more users and more severe ICI. Optimal precoding outperforms Wiener beamforming from middle SNR to high SNR. The gain is obtained at the cost of more backhaul link capacities required and a higher scheduling complexity.

Conclusion

In this article we explored the C-RAN service cloud logical architecture and the C-RAN multicell cooperation scheme. On one hand we propose the concept of a service cloud and a three-layer logical structure to make centralized processing more efficient, thus facilitating service provision. On the other hand we propose a condition number-based user pairing algorithm and a parallel implementation for optimum linear precoding in C-RAN, which utilizes extensive computation resources offered by the cloud platform to improve system performance. Compared to traditional algorithms designed for a specific signal processing platform, the proposed scheme matches well with the C-RAN architecture, as it manages interference efficiently and accelerates the cooperation processing in parallel. The simulation results show a higher spectrum efficiency is achieved.

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