Overview of Cloud RAN

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Abstract

Featuring centralized, collaborative, cloud and clean system, the cloud RAN (C-RAN) is deemed to be one of the most promising evolution trends towards future network. This paper provides an overview on the study progress of C-RAN, covering the major challenges, the potential solutions, the initial study results and the relevant activities in the industry and academia. There are two key challenges. One is the fiber consumption due to centralization feature and the other is the implementation of virtualization. While WDM is the most promising solution to address the fiber consumption with several successful trials by operators, for virtualization, there are still several challenges, including optimization on hypervisor, operating systems, management functions and I/O virtualization before realizing C-RAN cloudization.

1. Introduction

Data explosion in the big data era is in fact putting operators in a dilemma situation. Operators have to spend huge investment on network infrastructure upgrade to accommodate the explosively increasing traffic, resulting in a significant increase of the total cost of ownership. Operators, however, are not seeing proportional revenue growth with the data traffic. Under the circumstance, traditional RAN architecture where a dedicated equipment room with supporting facilities is needed for each base station is facing more and more challenges and issues for network deployment and operation, especially for LTE.

First, LTE site density is higher and thus requires more such equipment rooms, which is increasingly difficult to obtain since available real estate is becoming scarcer. Moreover, LTE suffers much more severe interference issue than 2G and 3G networks due to its universal frequency reuse OFDM nature and its higher cell density. Existing collaborative technologies such as joint transmission or joint reception can not perform effectively under traditional architecture with X2 interface which is of low bandwidth and high latency. Last but not the least traditional base stations are deployed for their peak scale to accommodate the peak traffic. This practice, however, due to the time-varying nature of the traffic, not only lowers the equipment utilization efficiency, but also greatly increases the power consumption unnecessarily.

Featuring centralized, collaborative, cloud and clean system, the cloud RAN (C-RAN) [1, 2] is first proposed by CMCC to help operators to address the above-mentioned challenges. A C-RAN network centralizes the BBU processing resource together into a pool so that the resource could be managed and allocated dynamically on demand. C-RAN offers many benefits to operators such as energy saving, TCO reduction, improved spectral efficiency and resource efficiency, and facilitation of service on edge.

C-RAN has provoked much attention and study across both industry and academia and is deemed as an essential evolution trend towards future wireless networks. This paper provides an overview on C-RAN study. The definition of C-RAN will be given in Section 2. In Section 3 the key challenges for C-RAN are analyzed with preliminary study results of the potential solutions. Then the global landscape of C-RAN study is described in Section 4, followed by the conclusion in Section 5.

2. Definition of C-RAN

With distributed BS as the basic component, a C-RAN system centralizes different baseband processing resource together to form a pool so that the resource could be managed and dynamically allocated on demand on a pool level. Fig. 1 shows the C-RAN architecture, which consists of three parts.

- BBU pool: A BBU pool is located at a centralized site and consists of time-varying sets of “soft” BBU nodes. A soft BBU is a BBU instance in a traditional network where processing resource and capability is dynamically allocated and reconfigured based on real-time conditions (e.g. traffic status).

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- Remote RRU networks: RRUs are the same as in traditional systems to provide basic wireless signal coverage.
- Transport networks. A transport network provides a connection between the BBU instance in a pool and the RRU. It could be of different forms depending on practical situation and scenarios. Some examples include direct fiber connection via dark fiber, microwave transmission, or fiber transport networks.

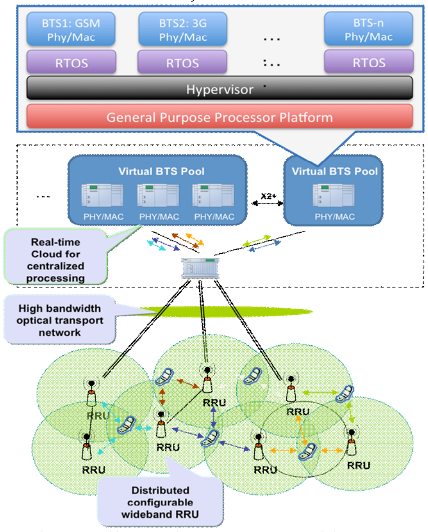

Fig. 1. Illustrative C-RAN architecture

Centralization, which is to aggregate different BBU into the same equipment room with shared facilities, is the basic feature in C-RAN networks. Resource virtualization is the most distinguished features of C-RAN. Unlike traditional RAN systems in which computation resources are limited within one BBU and therefore cannot be shared with other nodes, in C-RAN these resources are aggregated on a pool level and can be flexibly allocated on demand. This feature, very similar to cloud and virtualization concept in data center, is called resource "cloudization".

Some advantages of C-RAN can be directly derived from the centralization feature. Since there are much less equipment rooms in C-RAN compared to in traditional networks, the network deployment can be sped up. Furthermore, the facilities such as air-conditionings can be greatly saved, which contribute to the reduction of TCO, especially power consumption. In the long run when the virtualization comes to reality, the resource can be dynamically allocated on-demand, which will not only improve the resource and spectral efficiency, but also help with energy consumption.

3. Challenges and solutions for C-RAN

This section analyzes the major challenges as well as potential solutions for C-RAN realization.

- **Challenges to realize centralization**

Centralization scale of several dozens or several hundred carriers requires a large number of fiber resource if using dark fiber solution, i.e. direct fiber connection. For example, in a TD-LTE system with 20MHz bandwidth and RRUs equipped with 8 antennas (most common scenario in the CMCC network), the Common Public Radio Interface (CPRI) data rate between one BBU and one RRU for one TD-LTE carrier transmission is as high as 9.8Gbps. When considering both UL and DL, then 4 fiber connections would be required with 6Gbps optical modules. Since usually one site consists of three sectors with each supporting at least one carriers, the number of fiber connections for one site is as high as 12, which is difficult to achieve by most operators due to limited fiber resources. Therefore, an effective transportation solution is needed to minimize the fiber consumption.

There exists several potential solutions thanks to the advance in transportation area, including wavelength-division multiplexing (WDM), millimeter microwave transmission, optical transport networks (OTN) and so on. The major challenges when adopting any transport solutions are to meet CPRI's requirements, especially the jitter and synchronization requirements. WDM solution is the most promising among all due to the maturity of the industry and the large capacity. In some scenarios where it is either too expensive or even impossible to deploy fiber, microwave transmission may come to play a role as the last 100 meter solution. As for OTN, it is also a potential candidate solution. However, OTN network usually introduce relative large latency due to optic-electric domain conversion, which may undermine CPRI's performance.

Currently a few operators have adopted WDM solution to enable the large-scale C-RAN deployment. For example, CMCC demonstrated the WDM capability in the TD-LTE C-RAN field trial with 18 carriers centralized. It turned out that to transport 18 TD-LTE carriers only requires 3 fiber cores, which is much less than dark fiber solution which will consume 72 fiber cores (refer to the example above). In addition, WDM solutions can provide powerful O&M capability and support various protection schemes such as 1:1 or 1+1.

- **Challenges to realize virtualization/cloudization**

C-RAN's core feature is resource cloudization in which processing resources can be dynamically allocated to form a soft BBU entity. Given current vendors' proprietary and closed platforms, it is advantageous to develop a new BBU platform based on virtualization technology found in modern data centers.

A reference system architecture that uses concepts from data center virtualization technologies is proposed in Fig. 2 in order to realize base station virtualization. As shown in Fig. 2, the baseband resource pools are deployed on multiple standard IT servers. On each physical server there is an additional dedicated hardware accelerator for the computation-intensive physical layer function processes. The additional hardware accelerator design is required to meet the strict real-time requirements for wireless signal processing. The L2/L3 functionalities are implemented through Virtual Machine (VM) in a virtualization environment. Additional user applications such as CDN, Web Cache can be also deployed on the open virtualized platform in the form of VM.

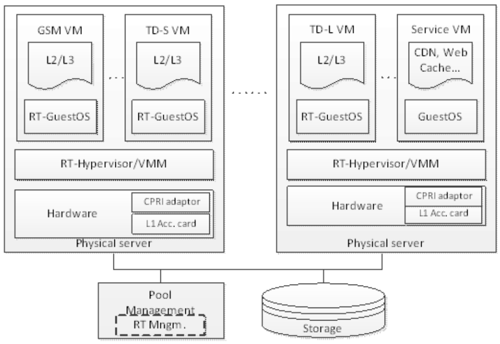

Fig. 2. RAN virtualization

Despite the simplicity of virtualization idea, the implementation is more difficult. Wireless communication is distinct from IT data centers in that wireless communication has extremely strict requirement on real-time processing. For example, for TDD-LTE systems it is required that an ACK/NACK must be produced and sent back to the UE/eNB within 3ms after a frame is received. Traditional data center virtualization technology cannot meet this requirement. Therefore, applying virtualization to base station requires careful design and special optimization on key function blocks. In particular, some challenges are identified as below.

- Optimization of operating systems and hypervisor in order to meet the requirements of real-time mobile signal processing, i.e. RT-OS and RT-Hypervisor with minimal and stable latency and jitter as well as optimum virtualization overhead.
- Optimization of virtualization management functions to fulfill the real-time constrains, e.g. VM live migration and dynamic resource orchestration with real-time signal processing.
- I/O virtualization to improve the VM's I/O performance and its compatibility with live migration.
- Design on virtualization granularity, taking into account various factors such as the correspondence between the VM and carrier and the requirements on carrier cooperation.

As the first step to address the real-time requirement, Intel, together with some partners, just released their latest study on optimizing the interrupt latency of a virtualized C-RAN [3]. Interrupt latency is the latency between the time when the server receives the interrupt notification and the time when the CPU starts the processing. Traditional value is on the order of several hundred microseconds. With optimization, it can be reduced to around 4 microseconds on average with 14us the maximum. It then greatly increase CPU's response time for wireless signal processing.

4. Global landscape of C-RAN study

- **C-RAN deployment**

SK telecom and Korea Telecom, the two biggest carriers in south Korea which is famous for rich fiber availability, adopts C-RAN centralization method to deploy the commercial LTE networks. Their C-RAN deployment has a high centralization scale. The LTE network in Seoul is centralized into around ten central offices with each supporting on average several hundred LTE carriers. In Japan with similarly rich fiber resource, DoCoMo has released a public release claiming their plan of using C-RAN for future LTE-A deployment.

- **C-RAN in SDOs**

In 2009 a dedicated C-RAN project P-CRAN was founded in the alliance of Next Generation Mobile Networks (NGMN) [4]. Led by China Mobile and received extensive supports from both operators and vendors, this project aimed at promoting the concept of C-RAN, collecting requirements from operators and helping build the ecosystem. The project was closed at the end of 2012, releasing four deliverables to the industry. Through the deliverables, the advantages of C-RAN in saving TCO cost and speeding up site construction are well understood. These deliverables also include the C-RAN requirements and initial study on key technologies as well as the potential SDO impact.

In 2013 NGMN extended the study on C-RAN in a C-RAN work stream under the project of RAN Evolution. On the basis of previous C-RAN project, this work stream aims at further detailed study on key technologies critical to C-RAN implementation, including BBU pooling, RAN sharing, function split between the BBU and the RRU, and C-RAN virtualization. In addition, the requirements on C-RAN fronthaul are specified.

Another organization worth mentioning is Network Functions Virtualisation (NFV) Industry Specification Group (ISG) under the auspicious of European Telecommunications Standards Institute (ETSI). Founded in 2012, this ISG is devoted to the development on the virtualization requirements and the system architecture. The idea behind NFV is to "consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Data centers, network nodes and in the end user premises" [5]. So far this ISG has attracted more than 150 members from not only telecom but also IT industry.

In addition, there are several C-RAN related projects under European Commission's Seventh Framework Programme (FP7). For example, the iJOIN project deals with the interworking and joint design of an open access and backhaul network architecture for small cells on cloud networks [6]. Another project, Mobile Cloud Networking (MCN) aims at exploiting Cloud Computing as infrastructure for future mobile network deployment, operation and innovative value-added services [7].

5. Conclusions

In this paper, we provide an overview on the study progress of cloud RAN, covering the major challenges and the potential solutions, as well as some key progress. There are two challenges to address for realization of C-RAN. One is fiber consumption issue due to centralization feature, which, thanks to the advancement in transport industry, is gradually overcome. The other is virtualization adoption in C-RAN to ultimately realize dynamic cloud-level resource allocation and management. A reference architecture of C-RAN virtualization is proposed and initial study has demonstrated order of magnitude reduction in terms of the interrupt latency. In the future, there are still lots of challenges to overcome to realize cloudization, including optimization of hypervisor, software architecture design and so on.

6. Acknowledgements

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7. References

1. Jinsong Wu, Sundeep Rangan and Honggang Zhang, "Green Communication", CRC Press, 2013.
2. C. M. R. Institute, "C-ran: The road towards green ran," October 2011. [Online]. Available: labs.chinamobile.com/cran.
3. John DiGiglio and Davide Ricci, "High performance, open standard virtualization with NFV and SDN", Intel's white paper, June, 2013.
4. [Online]. Available: www.ngmn.org.
5. [Online]. Available: http://portal.etsi.org/portal/server.pt/community/NFV/367
6. [Online]. Available: http://www.ict-ijoin.eu/
7. [Online]. Available: http://www.mobile-cloud-networking.eu/site/