SUGGESTIONS ON POTENTIAL SOLUTIONS TO C-RAN

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EXECUTIVE SUMMARY

Following the high-level requirements identified in D2, in this document of „Suggestions on Potential Solutions to C-RAN“, some key technologies critical for C-RAN realization are studied. Starting from scenarios suitable for C-RAN deployment, major functionalities of C-RAN are presented, some of which distinguish C-RAN from traditional systems. To fullfill the critical functions and to exploit the potentials of C-RAN such as resource sharing, possible solutions are studied and suggested. The document ends with suggestion on how traditional RAN could evolve to C-RAN step by step and the trend on fiber transport networks.

In Chapter 3, we identified five deployment use cases of C-RAN, including large-scale CRAN deployment, small-scale deployment, super hot spots, indoor and train/railway scenarios. For operators of both abundant access fiber and sufficient aggregative-level fiber resource, a C-RAN system with either star/tree or ring topology could be quickly deployed for macro networks. While for operators without sufficient backhaul capacity, by using legacy site room a small-scale C-RAN could be introduced to increase network data capacity with the help of such techniques as cell split, overlay and so on. As for indoor environment, thanks to its features of small volume and quick and easy installation of a radio unit, C-RAN can also fit for indoor coverage. Finally, C-RAN could be expected in some special scenarios such as super hot spots and railway/train environment by making better use of techniques such as cooperative transmission and receiving, cell-sharing and so on.

In chapter 4, we started with analysis of key functionalities that a C-RAN system should possess. Firstly, thanks to the inherent feature of centralization of various hardware resources, cooperative transmission and reception is deemed to be more easily implemented. Secondly, a C-RAN system should have the ability of resource sharing for a more efficient utilization of different hardware resources. To this end, virtualization may be one promising technology and thus became one of the key functionalities of C-RAN. Finally, the remaining functions include multi-RAT support, reliability, common O&M and network sharing.

Following functionalities analysis, we then studied the design of C-RAN building blocks, i.e. DU/DU cloud, fronthaul networks and RU networks and how they could better support those key functions.

DU/DU Cloud is the core of a C-RAN system. In this document we suggested two hierarchical architecture of DU Cloud, based on GPP and non-GPP platform respectively. Furthermore, according to where to put L1 process function (in DU or on RU side for example) and whether there is pre-processing module or dedicated L1 processor (i.e. accelerator), we further propose five different cases of function split between DU cloud and RU networks.

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For fronthaul networks, different solutions are proposed taking into account different conditions and resources operators may have. For example, for area with plenty dark fiber resource, a direct connection between DU and RU with star topology is applicable. With limited dark fiber resource, an area may adopt fiber ring topology for single-RAT deployment while using WDM transmission ring for multi-RAT sites. For area with no fiber resource, transmission with microwave may be an option. In the future C-RAN RU-DU interfacing may evolve to better support commodity non-dark fiber solutions.

An RU node in C-RAN is quite similar to in traditional systems and in the context of C-RAN, one critical issue lies on power supply, which we suggested two solutions including local DC/AC power supply as well as remote HVDC power supply.

In the last chapter, we suggested three steps for a traditional RAN to evolve to C-RAN architecture gradually. We further suggest very briefly some trend on fiber transport networks.

It should be noted that the suggestions given in this document are not intended to be mandatory for C-RAN vendors or operators. Instead, it is a reference for C-RAN system implementation and deployment. To fit in different network's deployment scenarios in different area, vendors may have flexibility in their C-RAN solutions. The same principle also applies to operators in C-RAN deployment.

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1 BACKGROUND AND OBJECTIVES

This document describes potential solutions of the C-RAN system [1][2][3][4], starting with an overview of the new RAN implementation and deployment architectures that can satisfy the requirements defined in C-RAN D2 document. The objective is to provide a guideline to the industry in future roadmaps for C-RAN.

One major aim of this document is to show how to utilize new technologies such as common baseband unit for multi-standard processing, and inexpensive digital radio signal transportation over fiber, in the implementation as well as deployment of a C-RAN solution, to achieve the goals of reduced CAPEX, OPEX for quicker, easier, better and more effective RAN deployment.

Another major topic is to identify how the C-RAN solutions can make maximum use of existing RAN assets. The method of gradual upgrade/replacement of traditional BS systems with new RAN deployment methods should be studied. Seamless upgrade at minimum overall cost is wanted.

This document also lists a number of deployment use cases and identifies which C-RAN implementation options are expected to provide the highest benefits. Different deployment scenarios may have different RAN upgrade paths to the new RAN implementation and deployment. There might be different or mixed solutions of RAN for different deployment scenarios.

It should be noted that the suggestions given in this document are not intended to be mandatory for C-RAN vendors or operators. Instead, it is a reference for C-RAN system implementation and deployment. To fit in different network deployment scenarios in different area vendors may have flexibility in their C-RAN solutions. The same principle also applies to operators in C-RAN deployment.

The standardization of the C-RAN solution will be addressed in NGMN P-CRAN D4 document.

2 C-RAN SOLUTION OVERVIEW

The C-RAN is mainly composed of three parts: the distributed remote Radio Units (RU), Remote Radio Heads (RRHs) and antennas and the high bandwidth and low-latency transport network which connects the RUs to the DU Cloud. The DU cloud is composed of Digital Units (DU) which are also referred to as Baseband Units (BBU) these are centralized in one physical location for providing resource aggregation and pooling. Different RATs can be implemented on the C-RAN physical system. The core network functions may be outside the C-RAN perimeter and are not addressed in this document. We limit the descriptions of these interfaces to those specific to C-RAN implementations

Figure 1 shows the C-RAN architecture overview with external interface to core network:

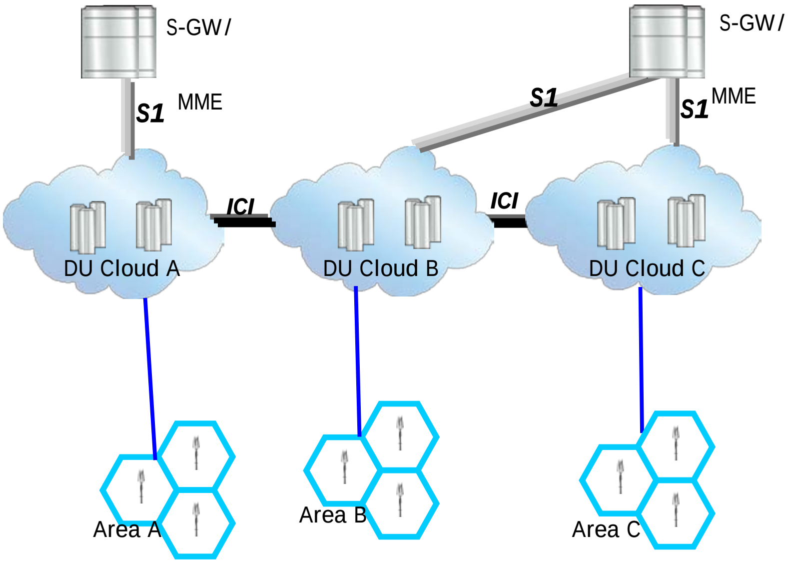

Figure 1: C-RAN high-level view

The RU is in charge of the radio functions from RF transmission and reception to digital baseband and adaptation to the transport network. It includes RF amplification, up/down conversion, filtering, A/D and D/A conversion and interface adaptation. It connects via optical transport networks to one or more DU clouds or to other RUs (daisy chaining). Additional functions can be included in the RUs to lessen the pressure on transport networks, such as

- RRU daisy-chain
- Data compression
- Functions related to cell-specific processing (e.g. FFT/IFFT, framing) or user processing

The optical transport network is composed of the physical fiber routes and the transport devices / cross connections.

The DU Cloud is composed of many identical DUs interconnected together. It provides the capacity to aggregate the processing power of DUs together and allocate the processing powers to real-time tasks of BS according to network load.

3 DEPLOYMENT USE CASES

This section describes a number of deployment use cases and identifies, for each of them, possible C-RAN implementations, and the potential benefits provided by C-RAN approach.

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- Large/medium scale C-RAN
- Small scale C-RAN deployment using legacy site room
- Indoor coverage
- Super hot spot coverage
- Railway/subway/ highway coverage

3.1 Large/medium scale C-RAN deployment

Some operators not only have abundant access side fiber resource, but also abundant aggregative level fiber. It means that CPRI (Common Public Radio Interface) data between RU and DU can easily be transmitted long-distance. More DUs can be separated far away from radio sites and be centralized to a main office. Large/medium scale C-RAN architecture can be introduced to deploy a new radio network which is independent with legacy networks.

Typical fiber topologies are shown in Figure 3-1. One is star/tree or alternative star/tree topology while the other is ring or alternative ring topology.

RUs and outdoor PSU (Power Supply Units) are deployed in all the radio sites with zero machine room solution. DUs (DU cloud) and transmission equipment for backhaul are deployed in DU centers. Therefore, some key issues need deep research, including ***how those centralized DUs evolve to DU cloud*** and ***how the fiber resource between DU center and radio sites are optimized***.

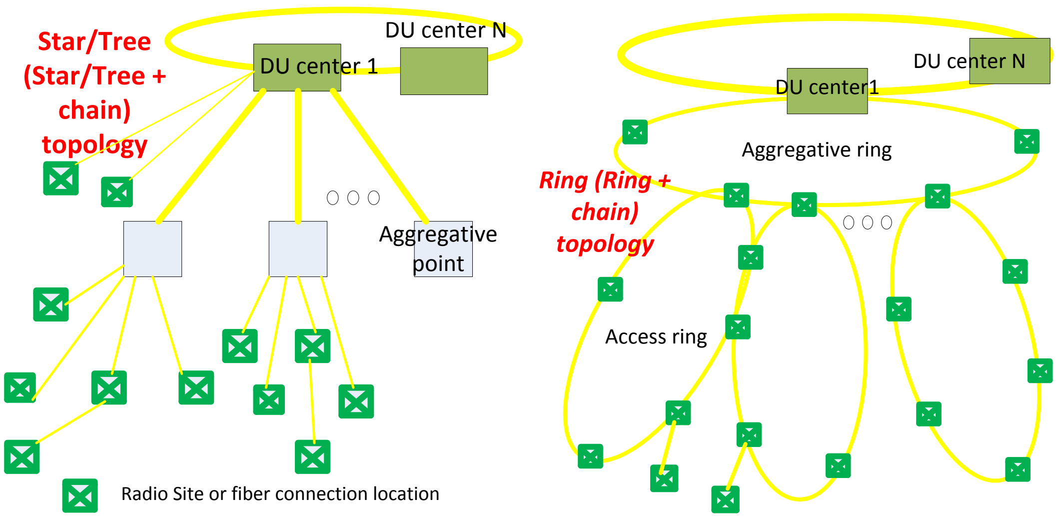

Figure 3-1: Large/medium scale C-RAN deployed for new macro network

3.2 Small scale C-RAN deployment using legacy site room

Some operators have a huge number of site machine room resources, but they are not willing to give up those legacy site rooms with air-conditioners, indoor power supply units (PSU) and site room monitoring equipments. On the other side, we can assume that a Gb backhaul transport network is not available when a legacy network has been deployed by a traditional distributed BTS (Base Transceiver Station) architecture. Under this situation, a small-scale C-RAN architecture can be introduced to operators' networks to supply sufficient network capacity and meet data big bang in a mobile internet era. A legacy site with three cells of the original network deployed by traditional distributed BTS can be taken as an example to explain how to evolve to C-RAN and enhance network capacity, as figure 3-2 shows.

The first method is using some new low power RUs with Omni antennas with outdoor PSU deployed in hotspots. Those low power RUs are connected with the legacy DU by fiber. When the hotspot regions have large capacity requirements the Omni cell can split to several small sector cells. This is a small scale C-RAN introduced for quick network deployment. It is a kind of heterogeneous network scenario (HetNet).

The second method is splitting a big macro cell into several small cells by adding new sites and reducing old cell coverage radius. It is a cell split scenario.

The third method is introducing a new frequency band or a new radio standard to provide large network capacity. It's an overlay scenario.

The methods mentioned above can be combined together, in which HetNet plus cell split plus overlay C-RAN can be united to form a fourth method.

Those new RUs in new sites are connected with the legacy DU or a new DU cloud deployed in legacy site rooms by a lot of fiber based on C-RAN architecture. But DUs or DU cloud locations don't have to change from legacy site rooms. Zero site room solution in new adding sites can be realized and huge TCO can be saved to give benefit for operators. Abundant access side fiber recourse needs to be deployed in this scenario.

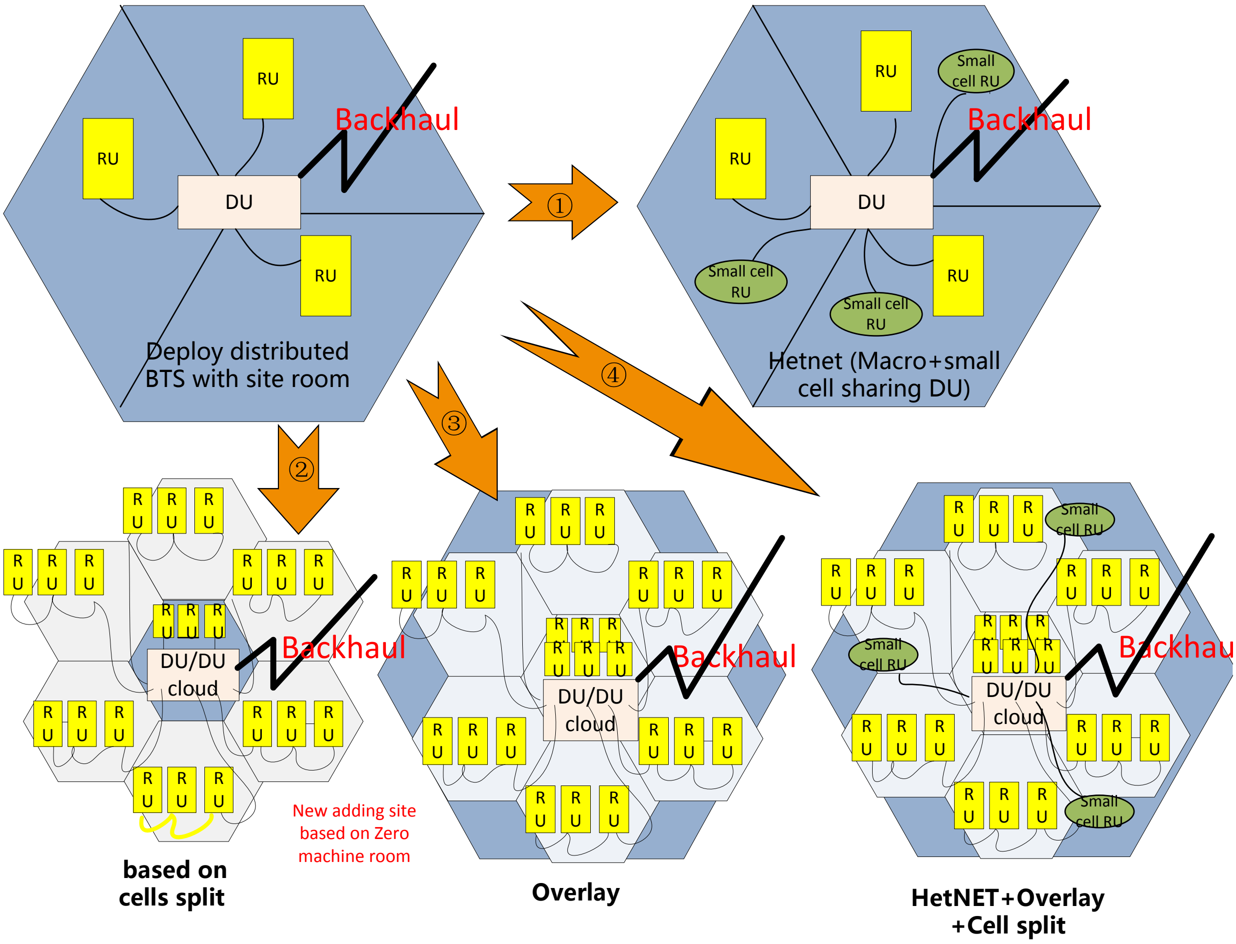

Figure 3-2: C-RAN deployed using legacy site room

3.3 Indoor coverage

A traditional indoor building coverage solution is based on a distributed antenna system (DAS) fed by repeaters which couple radio signals from one macro BTS. This old solution brings high interference to macro BTS cells and cannot supply large network capacity. With distributed BTS widely deployed, using RU as a signal source for indoor DAS has been a trend and is suitable for indoor/outdoor seamless coverage, as figure 3-3 shows.

RUs of different kinds of transmitter power class can replace repeater equipment with no change on DAS. RUs for indoor coverage can share the same DU with outdoor macro sites based on the distributed BTS architecture. When a building has low capacity requirement, indoor and outdoor regions can use co-cell technology with multiple RUs to reduce indoor /outdoor handover to improve network quality. When buildings need large capacity RUs for indoor coverage they can occupy independent cells by adding baseband processing resource and software update.

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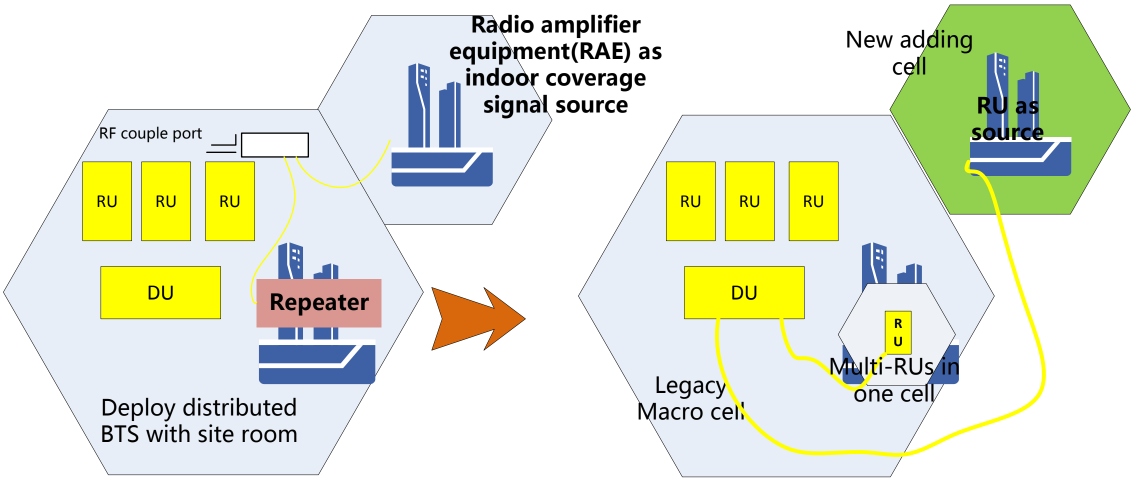

Figure 3-3: Indoor coverage based on traditional architecture

Signal source with DAS for in-building coverage has some shortcomings, such as high power loss due to complex cable feeder systems and thus cannot meet high data rate requirements for indoor environments in the future.

An innovative solution can be introduced based on C-RAN architecture as Figure 3-4 shows. A number of small radio units combined with antenna array units can be deployed on nearby ceilings and can be connected with the DU or DU cloud by fiber. In the majority of cases, the deployment of optical fiber in this environment is affordable, and therefore cost should not be an obstacle. The benefit of C-RAN can be introduced to in-building coverage. For instance, thanks to the shared DU resources among these in-building RUs, co-operative radio algorithms can be implemented to reduce interference between cells and improve overall indoor capacity.

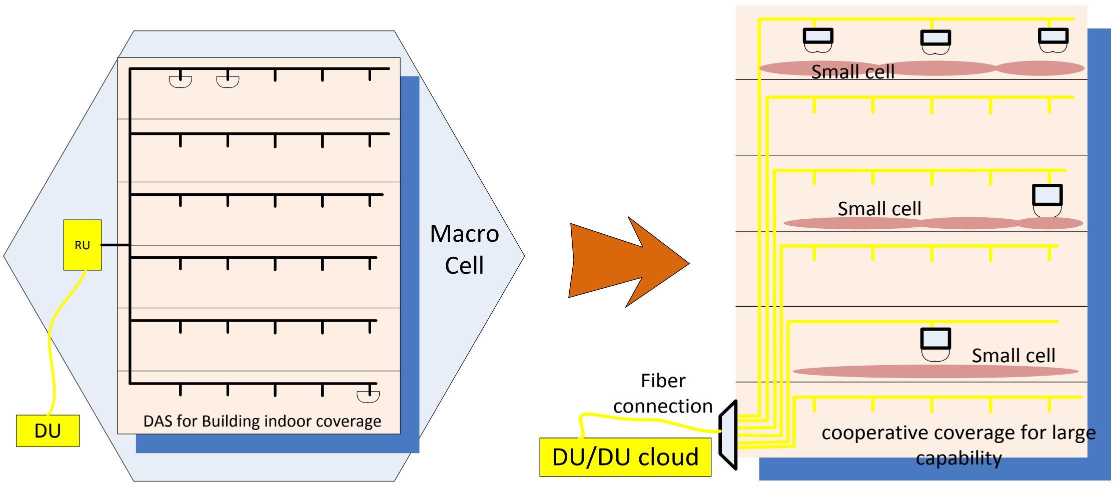

Figure 3-4: Indoor coverage base on an innovative architecture

3.4 Super hot spots

There are use cases where several hot zones are close to each other. Coverage of a stadium is an example of such an interesting use case. It is characterized by a high traffic demand in a relatively large area. The same kind of situation can be encountered in major transportation hubs such as train/bus/subway stations

This scenario is characterized by

- High subscriber density: 80,000 people, with high data capacity per subscriber
- Relatively large areas requiring several small cells to provide coverage
- Complex coverage (balconies, cement barriers)
- High interference, requiring advanced interference management between cells (possibly CoMP)
- Multi-tenant support
- Co-existence with a macro network

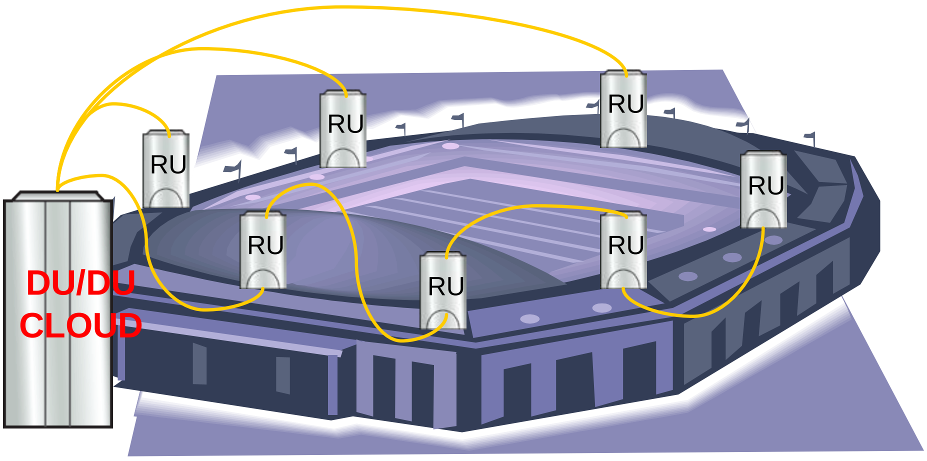

Figure 3-5: Stadium coverage

DU-RU interconnection can be direct or through daisy chaining.

A centralized approach is appealing for these kinds of scenarios since it simplifies the implementation of advanced interference management algorithms (ICIC, eICIC) and Cooperative Multi Point (CoMP). CoMP is expected to provide uniform coverage in this kind of difficult environment.

Again, the deployment of optical fibre in this environment is, in most cases affordable, and therefore cost should not be an obstacle.

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3.5 Railway/subway/highway coverage

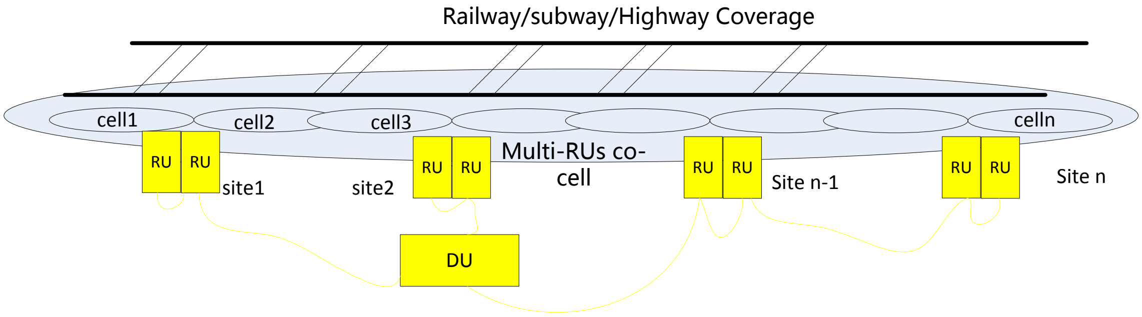

Figure 3-6: Railway/ subway/ highway coverage

In order to reduce UEs' frequently handing over between neighboring cells when moving at high speed which results in voice service or data download breakouts in the railway/subway/highway scenario, different RUs in different sites using C-RAN architecture can cooperate with each other and many macro chain cells can be combined to a super macro cell. In this burst communication scenario, network performance has higher priority than network capacity.

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4 SUGGESTION SOLUTIONS ON C-RAN SYSTEM IMPLEMENTATION

4.1 Key functionalities of C-RAN

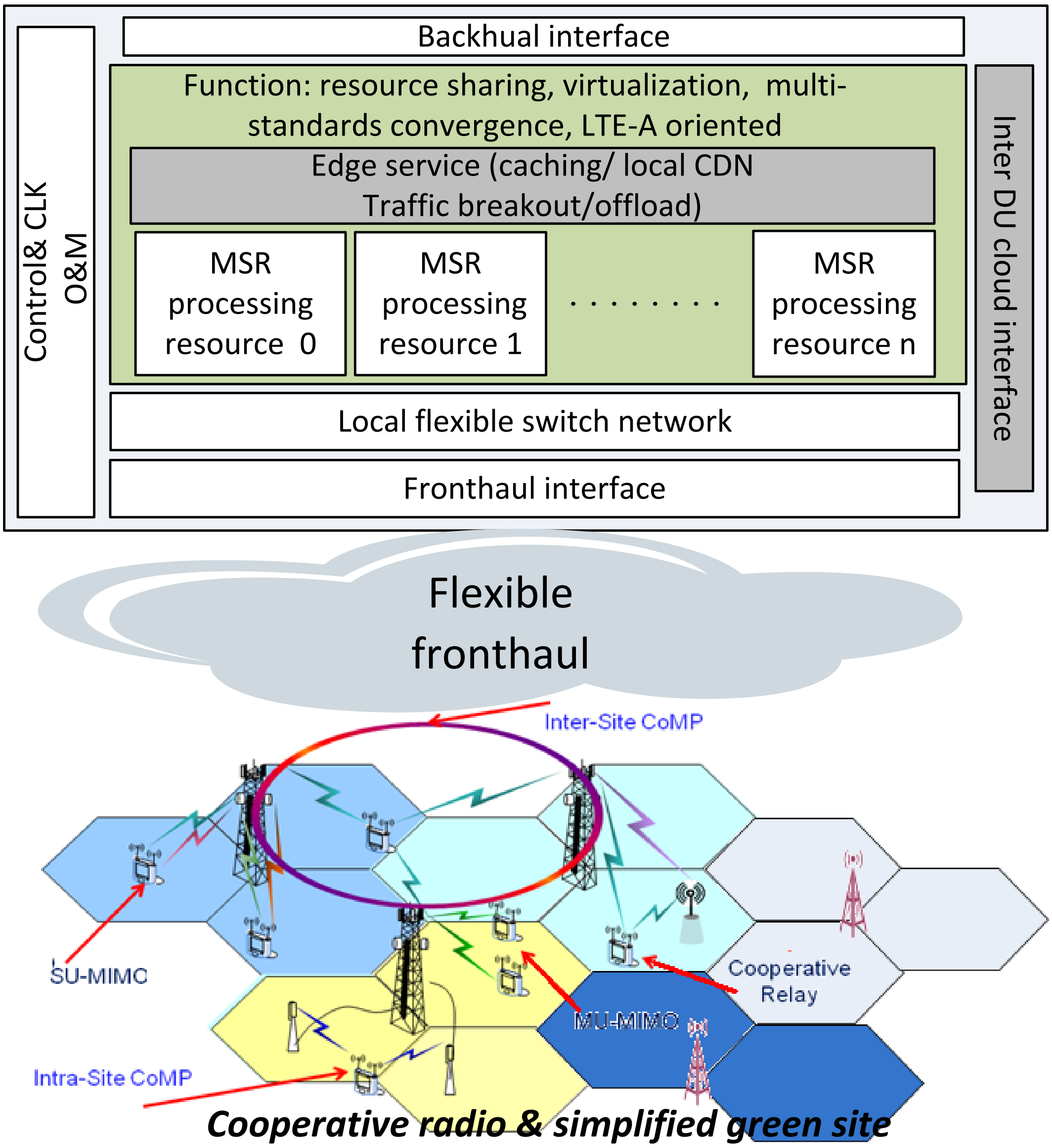

Figure 4-1: Overview of C-RAN functions

C-RAN has several C characteristics: Centralization, Cooperative radio, Clean system and Cloud computing. To this end, functions in a C-RAN system should include co-operative transmission and receiving, resource control and sharing, virtualization based on the GPP platform in order to allow managed execution of multiple workloads independent of underlying hardware platform, multi-RATs support, common O&M, reliability and network sharing - especially active RAN sharing.

4.1.1 Co-operative Transmission and Receiving

Coordination techniques such as coordinated multipoint (CoMP) transmission and reception is recognized as an efficient tool to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput [5].

Through the centralized processing in C-RAN, the joint processing becomes relatively easy. The joint processing includes not only CoMP defined in 3GPP, but also many other technologies such as joint scheduling, joint interference alignment/cancellation and other more advanced future technologies that could benefit from C-RAN architecture thanks to its centralization feature.

4.1.2 Resource sharing/consolidation

Resource sharing and consolidation is one of the key features of C-RAN for cost and power saving. Dynamic task/load migration is a possible solution to resource sharing/consolidation.

A "resource control" module in DU cloud controls and decides the migration procedure, including both the DU resource and inter-DU switch network in DU cloud.

The granularity of migration is implementation specific. For example, one cell sector with (L1+L2+L3) can be the basic migration unit. Alternatively, it can also be L1 that would be migrated when L2/L3 from several sectors are centralized and processed.

The migration could be explicitly implemented or implicitly supported. Besides, explicit Implementation means the DU cloud designer should consider when and how to migrate, and control all the procedure of migration of, for example, the L2/L3 status recovery, connection switch etc.

Implicit migration could be supported by virtualization technology. Underline hypervisors can monitor the status and load of DU and move the running virtual machine (VM) to other DU based on pre-defined strategy.

4.1.3 Virtualization

In the modern IT industry, virtualization plays an important role in cloud infrastructure. Virtualization provides virtual environments for guest OS and applications and separation between different OS despite them running on the same physical machine.

With virtualization, VM could be treated as an independent operating environment with virtually independent CPU, and I/O resource.

C-RAN is one kind of domain specific cloud technology, and can benefit a lot from virtualization technology. For example, one processing unit (e.g. one sector processing) could run in a virtual machine (VM). Furthermore, some core network applications and services can also run in DU cloud independent of signal processing in forms of different VM.

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Figure 4-2 shows an example of the concept of virtualization, in which hypervisor is the middle ware to manage VMs. Three independent guest operation systems are running on top of hypervisor. Different tasks are running in the VMs.

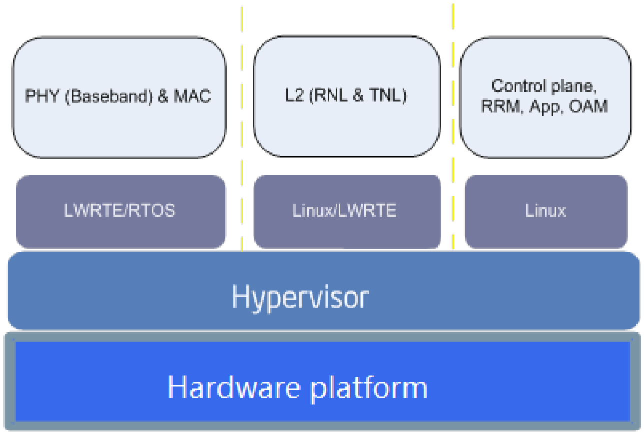

Figure 4-2 – An example of virtualization

4.1.4 Multi-RAT support

C-RAN should have the ability for multi-RAT (radio access technology) support in the same DU cloud for inter-RAT resource sharing and consolidation. multi-RAT includes GSM, UMTS, and LTE (or part of it depending on operators network).

In implementation, even though the detailed functions may be different from RAT to RAT, designers should integrate them in one physical device for multiple RATs support.

The DU processing unit cloud should be flexible enough to support multiple RATs. One possible scheme is to use Software-defined Radio (SDR) based DU to process any protocol. Alternatively, depending on the design, DU may require a hardware accelerator to off-load computation intensive tasks such as high throughput turbo decoder.

The accelerator together with SDR should consider multi-RAT support targeting at specific requirements from the operator's network (supporting all the RATs may be difficult).

The RAT specific accelerators should have as small an impact on resource sharing/consolidation of C-RAN as possible.

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4.1.5 Reliability

Several levels of reliability should be considered in the design of C-RAN system

- DU reliability

  Board level backup as one of solutions to improve the reliability of DU.

  As for GPP (General Purpose Platform) based DU, many techniques exist for reliability improvement such as robust data integrity, predictive failure analysis and more.

  Virtualization can provide certain levels of reliability for DU. It can separate the mal-functional tasks/OS and avoid the crash of whole DU.

- DU cloud reliability

  According to the requirements in NGMN P-CRAN D2, DU cloud should be able to work with a small number of DUs in mal-function (e.g. 10%).

  DU redundancy is one of the solutions, when a DU breaks down, the migration controller could migrate tasks to a backup DU in a real-time way.

  The number of redundant DU is design specific and depends on many factors such as the size of C-RAN, traffic load, and reliability of single DU etc.

  A local switch network inside DU cloud may be not necessary to be backup since it is usually highly reliable and has its own internal backup mechanism.

  DU cloud backup is also a solution for reliability.

- Power supply reliability

  In some areas, it is necessary to have a battery or diesel generator backup for DU cloud power supply to avoid system power off. It can improve reliability of DU cloud networks.

- Front-haul network reliability

  Different transmission deployments have different reliability. The ring topology can improve reliability of DU cloud network while a chain topology is fragile to fiber failure.

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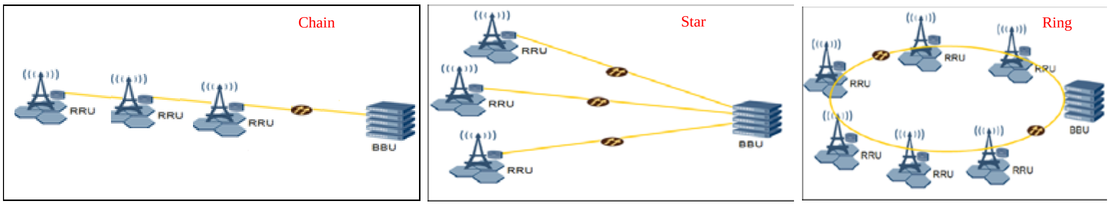

FFigure 4-3: Star/ring topology to improve DU cloud reliability

4.1.6 Common O&M

Traditional base stations (BTS) not only contain physical hardware but also contain logical services. From an OAM (Operation and Maintenance) view, the maintenance engineers can maintain the physical hardware and logical service simultaneously, based on base station network element. For C-RAN, a new solution is recommended. The physical resource and logical service are suggested to be separated completely: BTS is purely logical and only provides wireless service. Physical hardware becomes a resource pool to support wireless service and does not belong to any BTS. So the C-RAN management on OSS (Operation Supporting System) is also separated to two parts: Physical Resource Management and Logical Service Management. Based on BTS function, OAM engineers can only maintain the logical service. DUs and RUs are the physical resource that should be maintained, as the following figure shows.

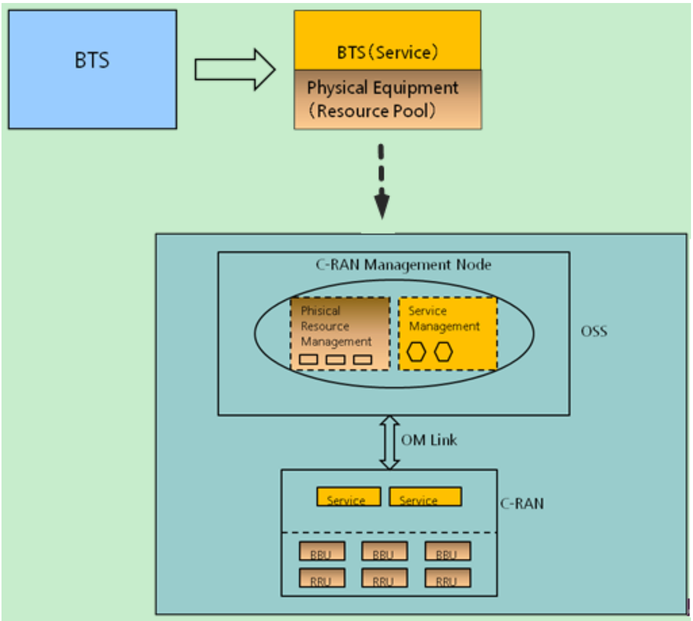

Figure 4-4: The sketch map of C-RAN management on OSS

The OSS solution for C-RAN could be different with the traditional BTS, the pros and cons need further analysis in the future.

4.1.7 Network sharing

To make better use of the spectrum and infrastructure resources, network sharing has been encouraged by regulators for minimizing environment impacts, e.g. overall emissions from multiple networks.

Network sharing is a practical requirement not only for traditional RAN but also for C-RAN. Network sharing can bring some benefits for operators, such as:

- *Reducing cost in radio access networks by sharing the radio sites and reducing the number of RUs for the same coverage area*
- *Quick sites acquisition for network expansion*
- *Fast deployment in new markets*
- *Balance between investment & return for rural area coverage*
- *Sharing of frequency resources*

All the sharing schemes available today or planned in the future should be available with C-RAN. These include:

- 2G Multi-Operator BSS (MOBSS, dedicated spectrum), 2G Multi-Operator Core Network (MOCN, shared spectrum), 2G Gateway Core Network (GWCN, shared spectrum)
- 3G Multi-Operator BSS (MORAN, dedicated spectrum), 3G Multi-Operator Core Network (MOCN, shared spectrum), 3G Gateway Core Network (GWCN, shared spectrum)
- LTE Multi-Operator BSS (MORAN, dedicated spectrum), LTE Multi-Operator Core Network (MOCN, shared spectrum), LTE Gateway Core Network (GWCN, shared spectrum)

Today network sharing is mainly on the form of static sharing between operators based on the agreement. In real life, due to the apparent fluctuations of the traffic load in temporary and geographical dimension, limitation exists for resource sharing flexibility.

In a later time framework, dynamic or semi-dynamic inter-operator resource sharing could work in a sense to make more sufficient usage of the resources. .

As a way forward, common OAM under discussion in 3GPP SA5 could work towards developing better communication between OAM from different vendors.

4.2 Solutions suggestions on C-RAN building blocks

4.2.1 DU and DU Cloud

From Figure 4-1, we can see that in a DU Cloud there are several logical building blocks.

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- “MSR (multiple standard radios) processing resource” is the signal processing resource implemented in DU. The mapping of MSR processing to DU is described in section 4.3.
- “Control, clock & OAM” is management entity in DU cloud, including several functions: control resource sharing/consolidation, clock, and OAM.
- “Local switch network” is the inter-DU network to facilitate antenna data to/from DU for resource sharing and joint processing.
- “Front-haul interface” is the interface between DU cloud and transportation network.
- “Back-haul interface” is the interface to core network.
- “Inter DU cloud interface” is the interface to other DU cloud, which is optional in implementation.
- “Edge service” is the services deployed in DU cloud together with signal processing DU, for example, cache/CDN, traffic breakout, offload etc. The function of “edge service” is optional in implementation.

4.2.1.1 DU

DU is a basic processing unit from a physical hardware’s point of view. The realization of DU is implementation specific and depends on the resource control strategy. For example, one box with multiple processing boards can be identified as one DU while one processing board itself could also be a DU.

For GPP (general processing processor) based approach, one DU could be a standalone server, or one (or more) CPU processing board in a ATCA (Advanced Telecommunications Computing Architecture) [6]box.

4.2.1.2 Hierarchical architecture of DU Cloud

From the implementation point of view, DU is the basic physical computation unit for tasks.

With the increase of the size of C-RAN DU Cloud, it becomes hard to switch antenna data from arbitrary RU to any DU. For joint processing, the required bandwidth for inter-node communication becomes much higher. Meanwhile, when the size of C-RAN reaches a certain level (e.g. more than 30 sectors), the resource sharing gain may become flat or marginal. Therefore it’s not economical to design a high speed full-connected DU Cloud. In order to balance scalability and flexibility, DU sub-cloud (cluster) may be used for a hierarchical design for DU cloud. Hierarchical architecture could be introduced by DU sub-cloud (cluster) as shown in Figure 4-4.

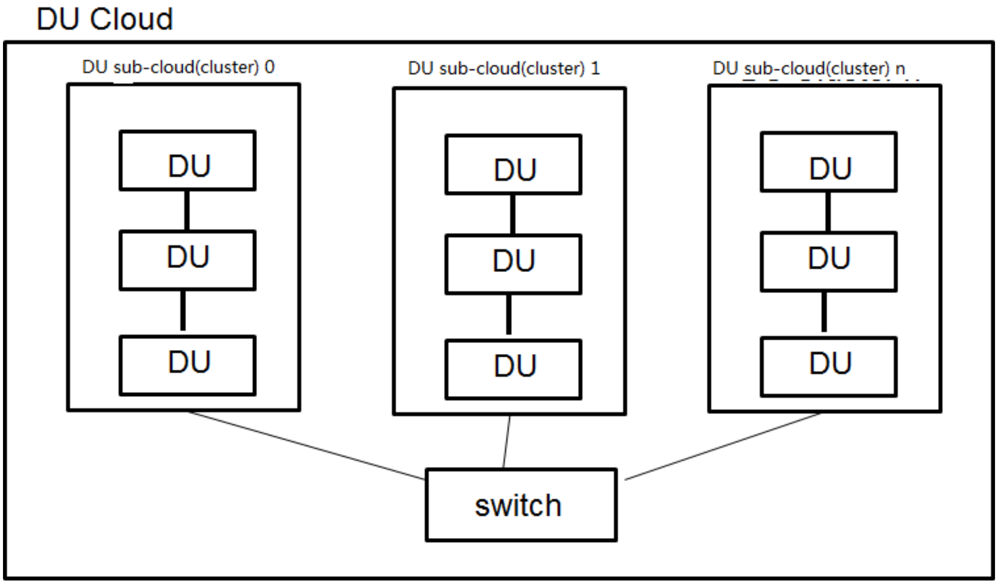

Figure 4-4: Illustration of DU cloud

Inside DU sub-cloud (cluster) the bandwidth could be much higher than the inter-DU cluster connection. So for JP-like processing, intra DU JP is preferred and intra-cluster JP may be applicable depending on the design. For example, joint scheduling could be implemented by intra-cluster DUs.

In order for simplicity, RUs could be connected to one DU cluster in a fixed way, and inside one DU cluster, the connection to DUs could be flexible by switch. Inter-cluster switch of RU connection is limited in terms of the number of RU and automation compared to intra-cluster switch.

With the increase of cloud size, operators can install more clusters or upgrade clusters (more DUs, or upgrade of DUs).

A DU cloud could be implemented based on GPP or traditional BS platform, which are described in section 4.2.1.3 and 4.2.1.4 respectively.

4.2.1.3 GPP based DU cloud

GPP (e.g. Intel x86 architecture) based DU cloud could be a powerful solution for several reasons.

- Evolving silicon technology and evolving micro architecture

  From 32nm to 22nm, and to 14nm, the silicon technology is evolving under Moore's law. New micro-architecture can further improve efficiency in terms of new instructions, processing pipeline, power consumption etc.

- Capability improvement in wireless signal processing

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Thanks to the advancement in silicon technology, GPP now can manager wireless signal processing with improved efficiency.

1) High efficient processing pipeline can deliver several 256 bits SIMD (Single Instruction Multiple Data) instruction per cycle. For example, it can process three add/sub SIMD instructions in one cycle, and load 2 SIMD data and save 1 SIMD data simultaneously.

   For example, in current implementation of 2048 points FFT/IFFT in one Intel SandyBridge core, the performance is 5737 cycles (or 2.86us in a 2GHz core). In the coming Haswell series, the performance will be boosted at least 2x because of 256bits fixed point SIMD

2) Powerful cache technology (three levels cache, L1, L2 and L3) as well as quite big size of cache (e.g. total 24MB cache in sever version) can translate some complex wireless algorithm into simple look-up table approach.

3) Multi-core and multi-CPU architecture

   Multiple cores (up to 10 cores in current server CPU) and multiple CPUs in one server provide another dimension to improve the processing capability besides SIMD parallel processing.

- All in one solution

  GPP has already shown appealing performance in service/application, packet processing, core network and L2/L3 processing. Together with signal processing in L1, GPP could be a universal solution for any tasks in C-RAN addressing all kinds of processing requirements from physical layer to application layer, control and data plane. The “all in one” features address the requirement of resource sharing and consolidation.

- IT Cloud technology

  GPP based IT cloud technology is a popular technology for data centers. C-RAN is one kind of domain-specific cloud technology yet it has many similarities with IT cloud. C-RAN can certainly benefit from the progress achieved in IT cloud technologies, for example, the design of reliability, scalability, virtualization, power saving etc.

As C-RAN is one kind of domain specific cloud, its architecture is somewhat different from traditional IT cloud even if C-RAN is based on GPP. In the subsection, a possible solution of GPP based DU cloud architecture is shown as an example in Figure 4-5 (note: concept solution for discussion), in which the distributed mode is utilized.

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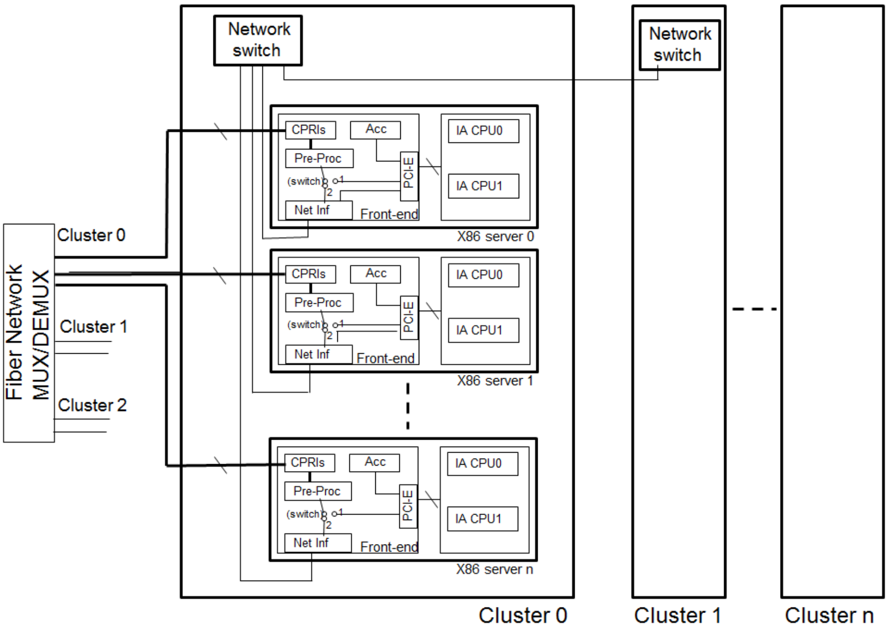

Figure4-5- Illustration of GPP based solution (distributed mode)

In the example, a DU is one x86 server which is equipped with two multi-core CPUs, with a front-end consisting of the CPRI interface, accelerator (optional), pre-processing and network interface. Pre-processing could be cell specific fixed functions like FFT/IFFT. Network interface can deliver the data after pre-process to other DUs for resource consolidation or load balancing. The network protocol could be high throughput Infiniband or Ethernet. A cluster can be mapped into a rack of servers on implementation with each rack having an individual network switch. Flexible task migration is possible inside a cluster and an inter-cluster switch is also provided. However, this switch has only relatively reduced bandwidth available.

Control & management function can run in a DU or a dedicated server to manage multiple clusters. Server redundancy is required for the system reliability from DU cloud's point of view.

The example above is using distributed mode in fronthaul to DU connection a centralized mode is also possible when a dedicated device acts as front-end.

4.2.1.4 Non-GPP based DU cloud

Several technological approaches are possible for DU clouds implementation. The approach discussed in this section is based on the use of application specific hardware and software. This is the development option taken by most RAN vendors for conventional distributed systems so far. It consists in using a combination of DSP, SoCs, FPGA and ASICs. The software running of these platforms is specific to the hardware.

Centralized RAN solutions can be derived from these conventional solutions. As explained in section 5.1, basic C-RAN solutions consisting in co-locating DUs, and connecting them to the RU using high speed low latency links

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does not require significant development effort. More advanced C-RAN architectures, enabling pooling gains, scalability, failover mechanisms and LTE-A features such as CoMP can also be derived with some more development efforts.

C-RAN resulting from evolutions of conventional distributed solutions combines the TCO benefits of C-RAN with high performance and low power consumption.

To illustrate how a conventional D-RAN solution can evolve to a C-RAN, two examples are provided, taking into account the requirements for flexibility and scalability from NGNM P-C-RAN D2.

The first example uses a central switching & controlling architecture as shown in Figure 4-6 (a) with the second example using part switching & hybrid controlling architecture in Figure 4-6 (b). The hierarchical design principle described in section 4.2.1.2 is also applicable here.

Example 1: In this case the DU cloud is designed as a super (e)NodeB/BTS and RUs are indirectly connected to DUs through top-to-bottom central switch equipment (CSE). DU cloud can be connected with another DU cloud by fiber for resource sharing and high reliability. This central switch architecture can support flexible DU-RU mapping. When one DU breaks out, other DU can sharing their resource to realize failure protect.

Example 2： RUs are directly connected with DUs to compose DU cloud. Each DU has independent S1/X2/Abis/Iu-r. DUs in DU cloud are connected to each other for co-operative processing. New CSU is introduced to DU cloud and has responsibility for the integrated OAM, inter-DUs baseband processing (BP) resource sharing and central controlling. The relationship between RUs and DUs in the distributed DU cloud architecture do not need to be changed. BPs resource in DU cloud can be shared and backed up in different DUs.

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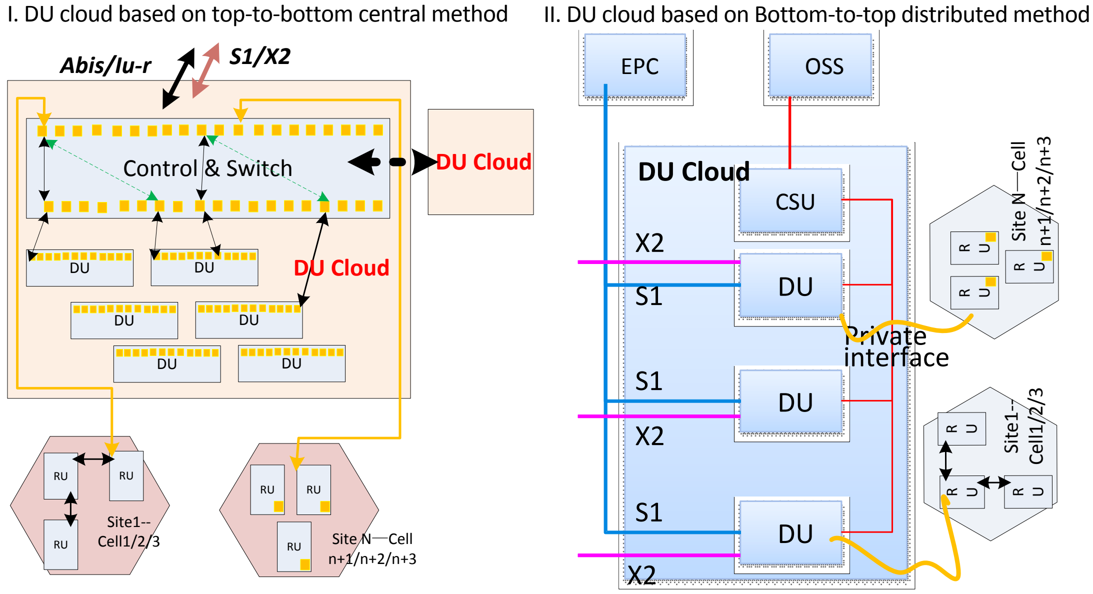

Figure 4-6: DU cloud based on traditional non-GPP platform

4.2.2 Connection between fronthaul networks and DU: distributed or centralized

The connection between fronthaul networks and DU could be implemented in a centralized or distributed manner.

For centralized mode, a central dedicated device is required to flexibly switch RU data (or after pre-processing) to or from DUs. With DU cluster design, the switch could be simplified.

For distributed design, RU directly connects to DU.

A DU should have dedicated frond-end interface logic to implement the function of antenna interface (e.g. CPRI), network switch interface (e.g. Infiniband/Ethernet) and optional pre-processing. One DU can connect several RUs depending on the capacity of DU and the number of connection ports.

In the dedicated interface logic, a switch function should be implemented, which can switch the antenna data or data after pre-processing to other DUs when the DU is powered off or encounters failure.

The comparison of distributed and centralized mode need further study from cost, reliability and performance point of views.

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4.2.3 Allocation of signal processing functions between RU and DU/DU cloud

As indicated in section 2, C-RAN consists of three basic building blocks: RU, DU cloud and transportation network. The allocation of functions between DU and RU has a big impact on the details of C-RAN architectures. Although there are various possibilities, five cases are listed here for reference.

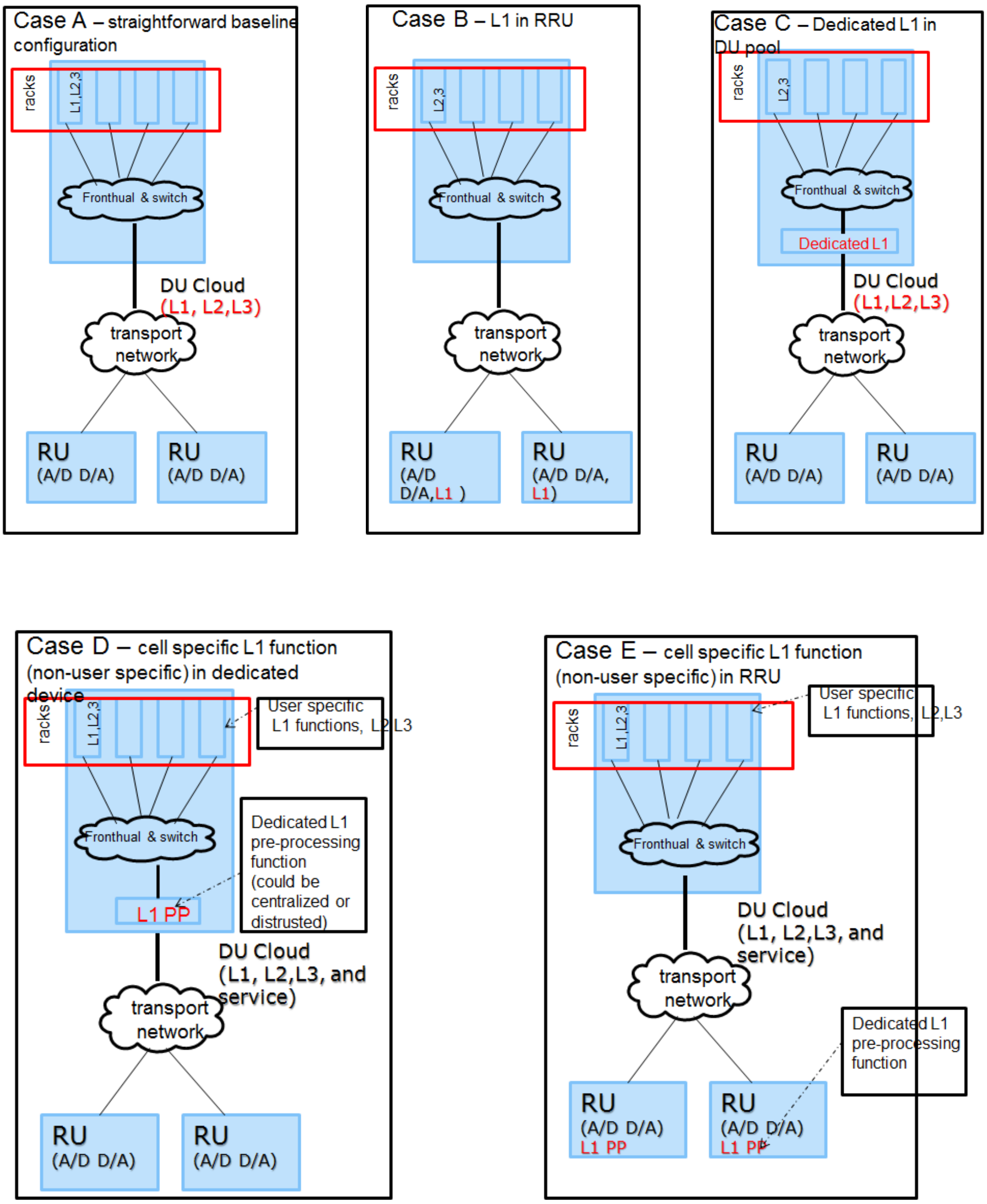

Figure 4-7: Five possible RU-DU function configurations

Case A: Baseline case: the functions in RU side are still traditional basic functions such as AD/DA, data compression while DU cloud does L1, L2, L3 and other related processing.

Case A is the baseline configuration of C-RAN which is simple and clear. However, some disadvantages exist, for example, high burden on the fiber network, high burden on the I/O of DU and high burden on the switch network in DU cloud for cooperation.

It's hard to save power by aggregating more sectors in one DU, especially during the night when the traffic is quite low because the raw RU data is relatively fixed no matter what the traffic load.

RU Data compression is a method to reduce the bandwidth requirement. It is still not efficient especially in term of useful payload in the spare time.

Case B: L1 in RU while moving L1 processing to RU.

The biggest advantage of this case is to greatly reduce the RU-DU data load, which relieves the burden on fronthaul fiber networks. However, since L1 takes major computation parts of C-RAN, if the L1 is implemented in RU, the overall benefit of C-RAN will decrease. For example, the flexibility of resource sharing between RATs or sectors will be reduced greatly. Advanced features such as CoMP, joint processing DAS etc. cannot be efficiently supported.

On-site maintenance or upgrade may be another problem. The interaction between MAC and PHY could also be complex.

Case C: Dedicated L1 in DU cloud but separated from general processing DU.

Same as case B, the resource sharing capability is weakened. However L1 in local DU cloud could have several benefits such as cost reduction in maintenance. An interface with high bandwidth is easy to implement to connect L1 and DU cloud. The interaction between MAC and PHY could be relatively easy.

For this case, the burden of fiber network cannot be reduced.

Case D: L1 pre-processing (PP) in DU cloud but separated from general processing DU.

Basic L1 pre-processing is the processing of sector/cell specific function such as FFT/IFFT, PRACH filter etc.

More advanced L1 pre-processing could do the "resource extraction" which only selects the occupied resource to the DU. For example, during night when traffic is low the number of extracted RBs (resource block) could be very small. As a result, the raw data from many sectors/cells could be pumped in one DU while another DU can be powered off to reduce power consumption.

L1 pre-processing could be implemented in a centralized (together with fronthaul interface), or distributed (together with DU) way.

The benefit of Case D is its flexibility to support the main feature of C-RAN – resource sharing and load aggregation while reducing the I/O burden of DU.

The main disadvantage of Case D inherits from Case A —-- the burden of fiber network is quite high.

Case E: L1 pre-processing (PP) in RU.

The case inherits the benefit of both Case B and D however the interaction between RU and DU could be complex.

Besides the mentioned five cases, some variations also exist. More detailed analysis is required for comparison.

4.2.4 RU and remote sites

A remote site consists of radio equipment, antennas, backhaul transmission equipment and other auxiliary equipment, such as power supply equipment, towers, monitoring equipment, etc. A typical change for C-RAN is that DU is no longer in the cabinet/box of the remote site.

4.2.4.1 Different kinds of RUs and their evolution

RU can be connected with DU by fiber under different topologies such as star, chain, tree, ring, ring+ chain, etc.

Different operators in different regions operate multi-RATs in different frequency bands and some of them have the requirement to refarm the old frequency band to deploy new radio standard. Thus RU needs to be designed to support multi-standards and multi-frequency bands. At the same time, those requirements such as higher ToC (top of cabinet) power of macro RU, less RU power consumption, higher RU/PA (Power Amplifier) efficiency, smaller RU volume, lighter weight and higher integrated level bring so many challenges to RU design. RU for macro-cell needs to support broader band such as 40MHz, flexible configuration for different radio mode and multi-mode in the same band to meet MSR standard of 3GPP. Other alternative RU (xTxR architecture) such as dual mode combined in one box for one sector, or single mode combined in one box for three sectors can be customized by operators' requirement. FDD RU has some difference from TDD RU because TD-mode for macro cell introduces smart-antenna mechanism and is usually designed as 8T8R. With the high-order MIMO introduced in LTE-A, 4T4R FDD RU in one band for one sector will be a good choice in the future.

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Compared with RU for macro-cell, RU for small cell is usually deployed with Omni-antenna. In this case the architecture of RU can be much simpler. For instance, 1T1R or 1T2R or 2T2R can be used for TDD systems. Pico/micro RUs are recommended to cooperate with macro C-RAN architecture by sharing the same DU resource for high network performance.

With multi-mode & multi-band radio introduced to operators' networks, more and more RUs and antennas will be deployed on the towers or roof-top for one-site location. It will not only bring network engineering complexity, such as the weight bearing and arrangement for so many RUs and antennas, but also cause the residents' focus attention on the radiation issue. So RU combined with passive antenna and its evolution to AAS (active antenna system) will be a trend in the future. One type of FDD AAS architecture is an array of antennas connected with distributed transceivers, PA/LNA and duplex, which can bring the vertical beamforming functions and flexible UL/DL coverage performance. AAS is not only suitable for macro-cell scenario, but also for small cells. Some big challenges need to be solved, such as weight, volume and power efficiency of AAS, testing performance and engineering optimization.

RU/AAS designed specifically for C-RAN need to focus on such key requirements in the future;

- Lower fronthaul data between RU and DU can be transmitted by traditional backhaul equipment
- RU has flexible interface and connection mode to support complex connection topology of RUs based on different site location, such as ring, chain, ring plus chain, tree etc.
- RU has monitoring interface to supervise status of other supporting equipment under zero site room solution and can transmit monitoring data through fronthaul network to DU/DU cloud side
- If ORI (Open Radio Interface) interface is accepted by industry, new RU architecture should obey this standard.
- Enhanced O&M function on RU side.

4.2.4.2 Power supply solution

There is not any DU in remote sites. Only the RUs need to be fed with power supply.

4.2.4.2.1 Remote sites with local power supply

1, AC Power Supply

There are 2 kinds of AC power supply scenarios for remote sites. The first one is that an outdoor AC-DC power box is deployed. This outdoor power box could be installed on ground or on the lower part of tower. The second one is an AC RRU where the RRU is deployed with AC-DC converter inside the RRU.

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For DU cloud-RU link, one CPRI aggregation module such as WDM equipment could be deployed on site. It could be passive or active.

2, DC Power Supply

The remote site could also get DC power supply directly from the power cabinet in the legacy site. For this scenario, no additional power cabinet or box is needed for remote site of C-RAN.

4.2.4.2.2 Remote sites with remote HVDC power supply

In this case, the remote site power supply is from a power supply centralization room that provides power for remote sites by HVDC (High Voltage Direct Current). The remote HVDC power supply can be used for sites in high speed railways or highways, rural areas or mountain areas etc. The key point of this solution is to have a centralized power supply that makes it easy and efficient on battery backup, maintenance, anti-theft and cost efficiency etc.

High voltage can reduce power cable loss. The power transmission distance could be longer with a bigger cable diameter at a price of increasing cost. The power consumption on cable should also be considered. Here is an example for power transmission distance and copper cable dimension.

HVDC (V)	RRU consumption(W)	RRU DC input(V)	Cross section size(mm^2)	Distance(m)
400	1200	220	6	5643

It needs to be considered if the remote HVDC power supply should be deployed with the trade-off for financial benefits.

4.2.4.3 Remote site monitoring solution

The power supply and environment equipment need to be monitored.

1, The power supply facilities include power supply equipment, batteries, air conditioners (if needed), diesel generators etc. General requirements are to support RS232/485 communication protocol and dry contact. The monitoring information includes alarm monitoring, configuration information, etc.

2, Various alarms of site equipment, including smoke alarms, burglary alarms, etc., usually need to be monitored for the relevant alarm information.

The monitoring information needs to be reported by RRU if there is no monitoring network in the remote site. The RRU then needs to transfer the information by fronthaul networks to DU cloud which the DU cloud sends to high level power and environment management systems via a backhaul link.

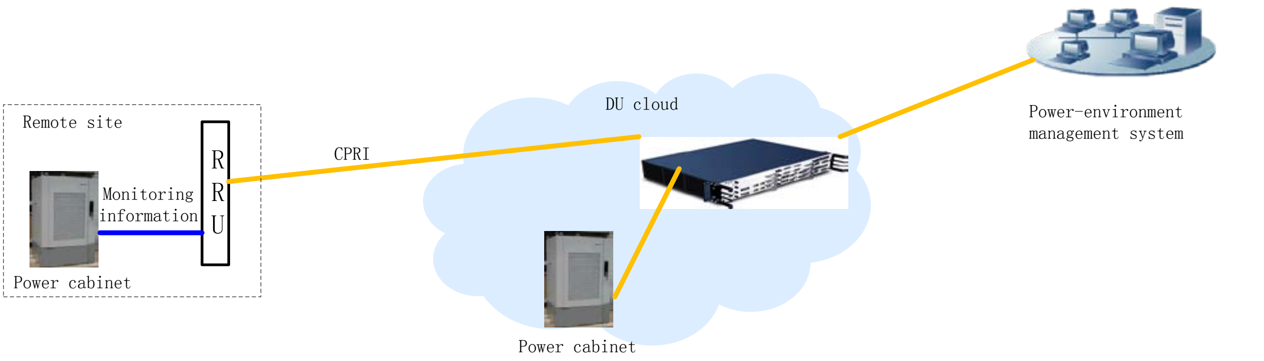

Figure 4-8: Remote site monitoring solution without locally deployed monitoring network

4.2.5 Fronthaul network solutions for C-RAN

In the following, different fronthaul network solutions are suggested taking into account different scenarios.

- **Area with Plenty Dark Fiber Resource**

If the fiber is not limited, the fiber star topology is recommended for C-RAN transmission as shown in Figure 4-9. The star topology could improve the reliability for transmission. Normally this topology is suitable for both single-RAT cloud and multi-RAT cloud in fiber unlimited area.

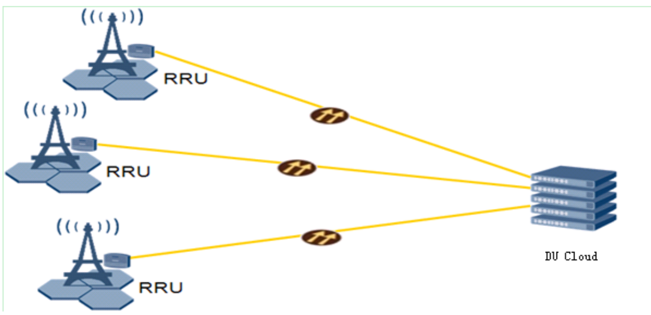

Figure 4-9: star topology of fronthaul with plenty dark fiber resource

- **Area with Available but Limited Dark Fiber Resource**

For this scenario, the available fiber couldn't support fiber connection from each RRU to Cloud. It's realistic for this scenario that each site has one pair of fiber for transmission. The fiber ring topology in Figure 4-10 (a) is recommended for single-RAT cloud. The three sector RRUs could be cascaded. Due to bandwidth limitation, the number of cascaded sites is limited.

The WDM transmission ring in Figure 4-10 (b) is recommended for multi-RAT sites. The active WDM (OTN) aggregates multi-standard sites' interface to save fiber. One outstanding advantage is maintainability for OTN solutions while the cost currently is high.

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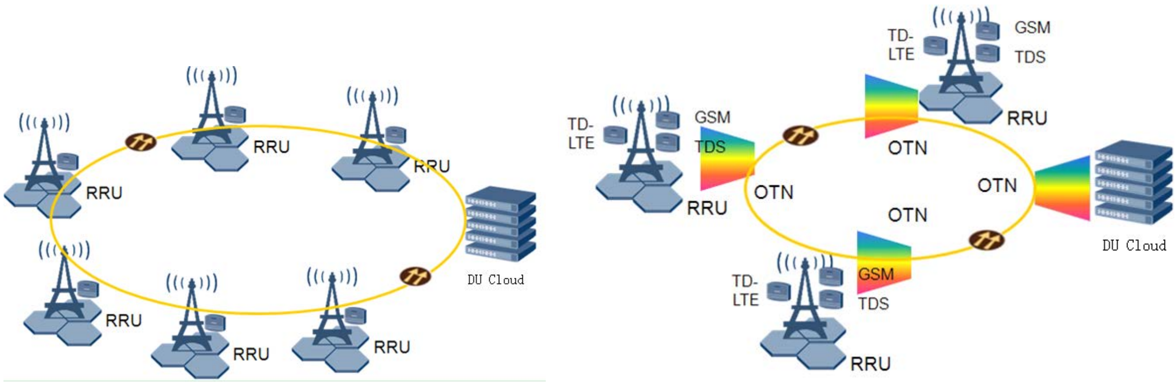

(a) Ring topology for single-RAT (b) Ring topology with WDM

Figure 4-10: Fronthaul solutions for area with limited dark fiber resource

- **Area with Limited Rental Dark Fiber Resource (with even limited fiber or rental wavelength)**

For this scenario, there are two sub-scenarios: sub one: - one pair of fiber for each RU site, sub two: each site has only rental wavelength.

For sub one, OTN ring solution is recommended as same as above.

For scenarios with rental wave lambdas, UniPON, as shown in Figure 4-11 could be a solution. For UniPON, the fixed access FTTx network could be shared with base stations. The transmission distance is also limited due to the attenuation of optical splitter.

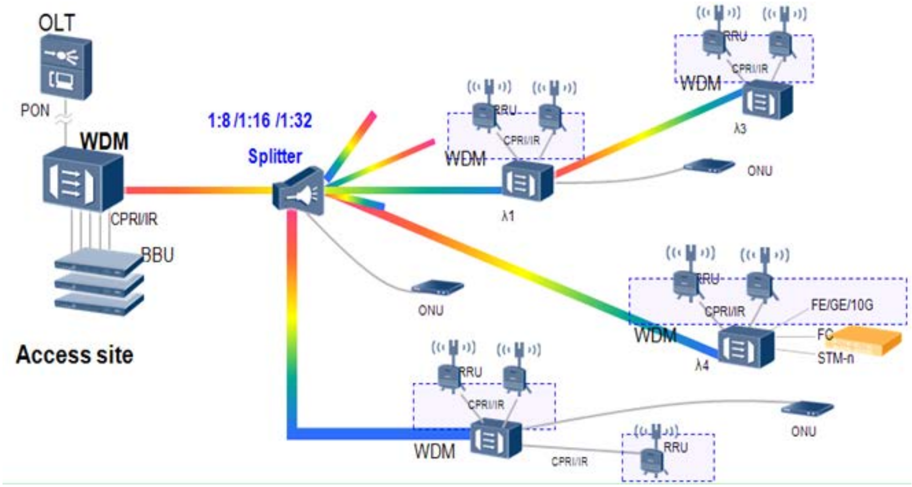

Figure 4-11: UniPON architecture as fronthaul solution for area with limited rental fiber

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- **Area with Limited Rental Transportation Bandwidth**

The L1 interface has less bandwidth compared with CPRI interface. It's possible to transport the L1 interface data on the limited bandwidth.

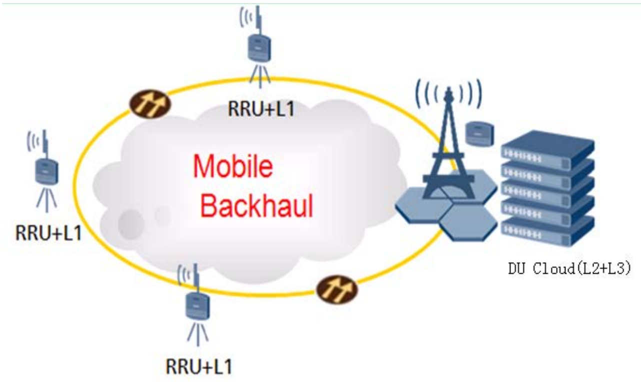

Figure 4-12: Fiber ring topology for remote L1 link

- **Area with No Fiber Resource**

In this area, only microwave or DSL (Digital Subscriber Loop) is available. Remote L1 architecture could be possible due to lower bandwidth and synchronization requirements. Microwave transportation is another solution.

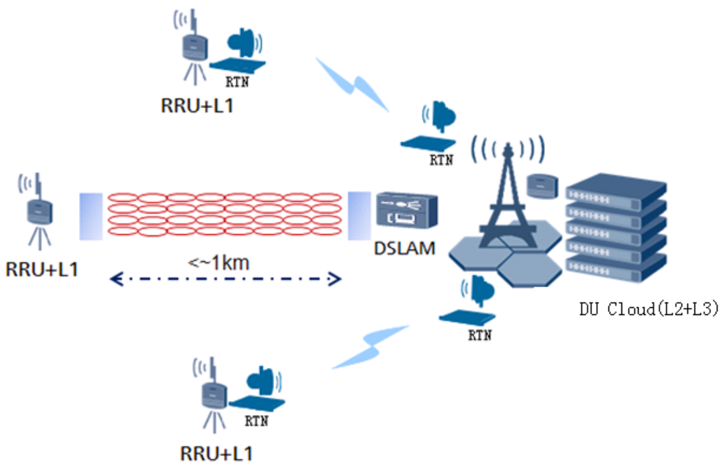

Figure 4-13: Microwave and other transmission solution for Remote L1 link

4.3 Mapping of functionalities to building blocks

The word "mapping" implies the relationship between functions that C-RAN should provide and the physical entities. The discussion in the previous two subsections in this chapter has already shed some enlightenment on this. In this

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subsection, we further complement on how the entities should better support the functions and what requirements the functionalities impose on the entities, i.e. the mapping.

C-RAN is an advanced architecture and especially suitable for CoMP JD/JT because it simplifies mesh high-cost backhaul network to simple fronthaul network. DU/DU cloud and RUs of C-RAN need to add more control/process resource to realize CoMP and other cooperative function in order to improve network performance.

Resource control function mainly lies on C-RAN, which should include such important parts as:

- Dynamic allocated processing resources between different radio standards in the same region.
- Dynamic allocated processing resources between different regions based on network load.
- Dynamic cooperative function according to network load status.

Three forms of virtualization in a C-RAN solution can be potentially co-existed on a DU cloud, based on GPP platform: hardware virtualization, network virtualization and application virtualization.

- Generally in hardware virtualization, a portion of the RAN hardware is virtualized i.e. a hypervisor is used to create and manage a virtual RAN layer. The hypervisor may be type 1 or type 2. Type 1 hypervisors run on bare metal and can support multiple Real Time Operating Systems (RTOSs). Type 2 hypervisors run on the top of RTOSs. The layer that is virtualized maybe a portion of the physical (PHY) layer or a protocol-oriented layer such as the MAC layer and above. The scope of virtualization is to allow the maximum possible utilization of the hardware, to enable graceful switchover in case of failures and to be able to manage the C-RAN infrastructure from a unified API.
- In network virtualization, network elements such as routers, switches, edge caching storage elements and transport resources are abstracted and combined into a pool that is managed by a network operating system. These virtual network components can then be assigned and managed by a unified API enabling network control policies to be easily implemented.
- Application virtualization is also within the RAN. It may be a useful feature when a runtime environment is needed e.g. network management application entities are replaced by a virtualization layer that will hide the centralization of the RAN until tailored software is written for this architecture. It may allow existing applications to run in the C-RAN without the need to rewrite the software.

Multi-RAT supporting of C-RAN should focus on the following additional parts:

- Different radio standards can flexibly run on the same DU/DU cloud hardware platform. SDR based DU/DU cloud could process any protocol.
- Fronthaul network can transmit Multi-RATs raw data using the same frame format.
- RUs of different radio standard and different band can be cascaded to supporting multiplexing mode in order to optimize fronthual resource.

C-RAN is a green network architecture, so 'zero site room' solution will be widely applied in the radio site side and monitoring equipment will share the same fronthaul with RUs. Common O&M in C-RAN needs focus on:

- Different O&M caring about radio side status, fronthaul status, RU status and DU/DU cloud status can be converged to one unified O&M.
- O&M focusing on one site can be evolved to common O&M focusing on site cluster.

Mapping of reliability function to C-RAN entities should focus on such parts as:

- Boards' backup for controlling and processing resource within a DU and DUs backup inside a DU cloud will be mandatory for C-RAN deployment.
- DU cloud backup in different DU centers for disaster will be optional, depending on operators' network cost.
- Power equipment backup for DU center and RU sites are necessary.
- If there is abundant fiber resource, ring topology of fronthaul will be a good choice to avoid transmission failure.

The mapping of network sharing functions to entities of C-RAN can be considered on the following aspects:

- Option1: Share DU resources, the fiber links and the RU sites with flexibility to manage its baseband and radio resources depending on the traffic load etc., and allow operators to share the surplus baseband capacity, spectrum and coverage with peers based on the policy definition inside DU (or OAM mirror entities)
- Option2: Share the RU sites with the possibility to maintain dedicated DU resources

  To facilitate multiple operators to share the RU resources while keeping the possibility to maintain dedicated DUs for each operator, the common language between the OAM of different vendors should be available with the aim to address the potential optimization of the overall usage of the shared radio

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resources. OAM or other entities inside the DU are required to allow joint radio planning between the RUs/Antennas from different operators inside the C-RAN architecture to optimize the network coverage.

- Option3: Share the DU resources with the possibility to maintain dedicated RU sites

5 EVOLUTION TOWARD C-RAN

5.1 From traditional RAN to C-RAN: step by step

Traditional RAN can smoothly evolve to C-RAN by three phases—DU centralization, DU pooling and Virtual RAN. Pooling and Virtualization of DU/DU cloud can be viewed as two different phases of DU cloud.

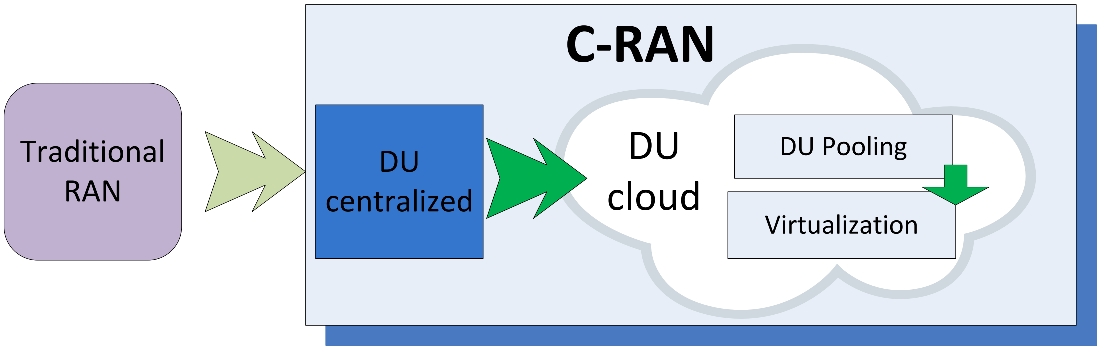

Figure 5-1: C-RAN evolution step by step

DU centralization is the first step through gathering the digital part of RAN in a single location. RF sites are connected to the RAN using high speed low latency links (typically fiber). This first step can start from a conventional RAN solution and does not require significant development effort.

DU pooling is the second evolution step. It brings the capability of load balancing between DUs and cost effective redundancy for protection against DU failure. DU resources are no longer dimensioned from peak requirements of each individual site, but from aggregated requirements of the cells covered by the pool. DU pool dimensioning takes advantage of the time and space distribution of traffic. The main benefits of pooling are on CAPEX, enhanced scalability and failover mechanisms. DU pooling includes LTE-A features for enhanced spectral efficiency and coverage fairness such as CoMP and ICIC.

Virtual RAN is the final evolution step where processing resources are virtualized. There has been no widely accepted definition of VRAN so far. However the main characteristics of VRAN are the use of standard technology for economy of scale and to reduce NW costs. Another aspect is to make

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applications independent of the hardware. VRAN also offers the possibility of enhanced scalability, easier evolution as well as openness to multiple actors.

5.2 Transport network evolution trends

There are a number of initiatives aiming at the definition of interfaces to allow interoperability between DU and RU from different vendors (e.g, ORI, Ir), or facilitating the development of compatible interfaces (e.g. CPRI). When these initiatives started, C-RAN was not yet considered. Therefore there are no provisions in the existing specifications aiming at facilitating C-RAN implementation.

The possible evolution trends of transportation networks for C-RAN may include:

- Routing capability: Being able to dynamically connect RUs to different DUs and DU clouds enables efficient load balancing and failover mechanisms. What is specific to this interface is the extremely low latency and high throughput requirements. This imposes some restrictions on the switching and transport technology that can be used. This approach makes it possible to reuse the same transport NW for all interfaces (e.g. S1 and X2 for LTE)
- Throughput reduction: conventional CPRI does not make an optimal usage of the transport resource. Several approaches are considered to make a more efficient use of the transport links. The first one consists of compressing the I/Q samples by resampling, rescaling and removing some unnecessary parts of the signal. A compression by a factor of 2 to 3 is achievable. The second possible method is to deal with partial L1 processing on RU side. By doing this, the throughput requirement on transportation links could be reduced greatly and furthermore, statistical multiplexing gains are achievable when several RUs are multiplexed on the same transport links.
- Configuration and management: evolutions need to support evolved radios and sharing of radios between several operators.

GLOSSARY OF DEFINITIONS AND TERMS

BTS	Base Transceiver Station
C-RAN	Centralized, Cooperative, Cloud and Clean RAN
CPRI	Common Public Radio Interface
DU	Digital Unit

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RU	Radio Unit
DAS	Distributed Antenna System
AAS	Active Antenna System
VM	Virtual Machine
BBU	Base Band Unit
BS	Base Station
CAPEX	Capital Expenditure
CoMP	Coordinated Multi Point
OPEX	Operational Expenditure
SDR	Software Defined Radio
RAT	Radio Access Technology
GPP	General Purpose Platform
O&M	Operation Maintenance
JP	Joint Processing
ORI	Open Radio Interface
HVDC	High Voltage Direct Current
RTOS	Real-time Operating System
WDM	Wavelength Division Multiplexing
RAN	Radio Access Network
RF	Radio Frequency
RRU	Remote Radio Unit
TCO	Total Cost of Ownership
SIMD	Single Instruction Multiple Data
PA	Power Amplifier

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