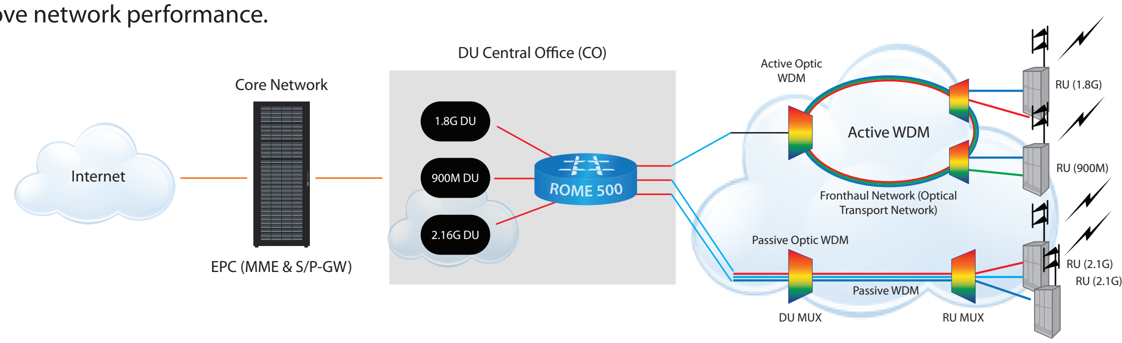
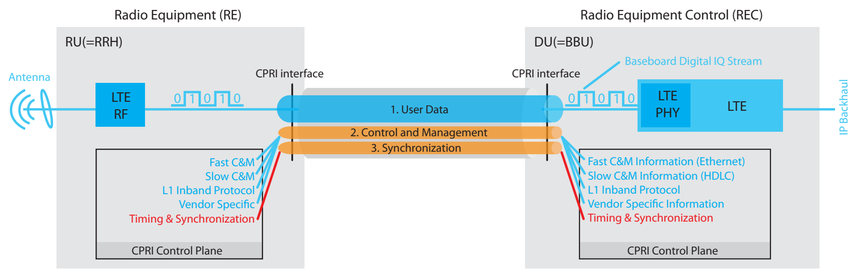
C-RAN is a new Radio Access Network (RAN) architecture with centralized baseband processing Digital Unit (DU) nodes for on-demand allocation of computation/processing resources. The C-RAN fronthaul network connects the DU pool and geographically dispersed Remote Radio Units (RUs). Information is exchanged between the Remote RU and the DU Pool over a Fronthaul transport network. The goal of decoupling the baseband processing (i.e. DU) from the RUs is to enhance redundancy and maximize operational reliability by utilizing DU pooling.

These DU pools are in the same room, floor or building to form a "DU Hotel", with a high-speed low-latency interconnection between nodes. In this way, C-RAN facilitates implementation of collaborative wireless radio networks to reduce interference and improve network performance.



The communication protocol between the DU central pool and remote Radio Units (RUs) is the Common Public Radio Interface (CPRI). The CPRI industry specification was established to define a publicly available specification that standardizes the protocol interface between the DU and remote RU. To manage the connected radios, the DU uses the CPRI standard for the DU-RU interface to transfer synchronization, radio signals and control and management signals.



The CPRI protocol is a full duplex serial data stream, with a transmit interface and a receive interface. For a C-RAN architecture to perform well, it is important the overall CPRI transport network is designed to keep latency as low as possible. The prevailing engineering guideline is to design the fronthaul network so that one way delay is below 75 microseconds. Since light travels approximately 1 kilometer in 5 microseconds, a 15 km fiber span would produce a one-way latency of 75 microseconds. Optical transport equipment that injects extra optical-electrical-optical (O-E-O) processing and multiplexing into the stream will add additional delay. Therefore, ideal fronthaul multiplexers would be optical Wave Division Multiplexing (WDM) systems that do not have unnecessary electrical signal processing.

The best physical facility for CPRI transport is dark fiber, because encapsulating CPRI into another protocol introduces too much latency and jitter. For areas with plenty of dark fiber, a direct connection between DU and RU via a star topology is appropriate. For an area with limited Dark Fiber access or rental wavelengths, a ring solution is an option, or a FTTx Passive Optical Network (PON) deployment could be shared with radio network towers.

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Since a radio tower site can consist of at least three sectors with each supporting at least one carrier, the number of fiber connections for one tower site can be as high as 12. As a result, it is necessary to find an optical transport solution which can carry the information stream between DU pools and RUs that consume as few fiber resources as possible. Examples of fronthaul networks that save on optical facilities are WDM and PON solutions.

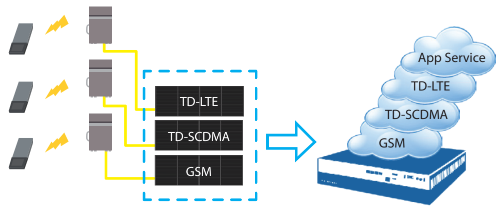
As the number of streams on a single pair increases, it becomes more important to have geographical redundancy and protection in case of a fiber cut. The two best options for CPRI transport multiplexing are Coarse Wave Division Multiplexing (CWDM) and Dense Wave Division Multiplexing (DWDM). CWDM technology opens a new possibility for a cost-effective deployment of C-RANs, because a high number CPRI signals can be transported into a reduced number of optical fibers using wavelengths and PONs instead of dedicated fiber links. CWDM systems allow multiple wavelengths to be transported on a single fiber by matching "colored" interfaces with the baseband and remote radio locations. Up to 16 CPRI wavelengths can be combined on the same fiber using a passive filter. The downside of CWDM is there is no inherent 1:N protection or scaling to support up to hundreds of CPRI links, and therefore becomes an operational challenge without automated fiber switching at the physical layer protecting the CWDM infrastructure.

Fiber Management Challenge of Centralization

Centralization is critical to realize all the envisioned features of C-RAN. Centralization aggregates various DU technologies into a pool of sharable equipment on demand. Centralization scale of several dozens or several hundred Remote Radio Units (RRUs) requires many fibers for direct fiber connections. It is also important that a fronthaul solution provide 1:N backup mechanisms in case of fiber failure.

Next Generation Flexibility, Protection, Provisioning and Load Balancing

The next generation Mobile Network Operator (MNO) Software Defined Network (SDN) C-RAN model helps spin-up the Software Defined Radio (SDR) DU Virtual Machine (VM) computational resources based on the CPRI optical interface on a given port.



Traditional baseband equipments

Software Defined Radio based on Virtualized Cloud Platform

SDR-VM C-RAN equipment coupled with Automated Fiber Switching products makes expensive radio and processing equipment more effectively shared, reducing capital and operational expenditures. For example, as the size of C-RAN DU Cloud increases, it becomes much more difficult to switch data from an arbitrary RU to any DU. 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 without an optical fiber flexibility point. Therefore, it is not economical to design a high-speed non-blocking interconnected mesh DU Cloud that has no fiber switching capability. To balance scalability and flexibility, DU sub-clouds (i.e. clusters) can be used for a hierarchical design for the DU cloud at the CO as shown in the following diagram:

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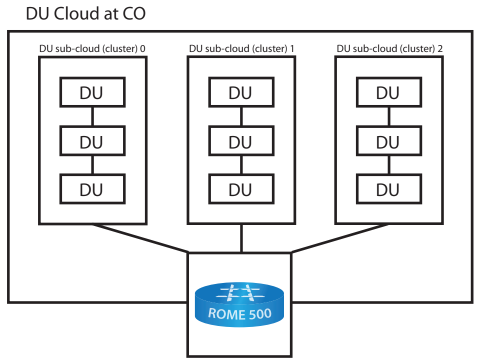
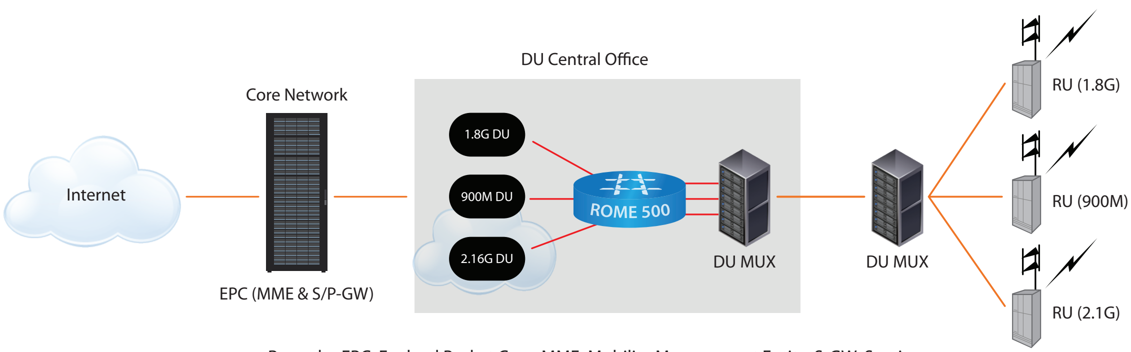


With larger cloud sizes and automated fiber switching technologies, operators can install more clusters or upgrade clusters (more DUs or upgrade of DUs) faster than with outdated manual optical patch and cross-connect processes and procedures. The ROME automated fiber switching product collocated with centralized DUs provide significant DU equipment pooling gain to more efficiently utilize DU equipment, and reduce capital costs. This means that DUs whose CPRI interface links were only partially filled from a RU cell site can be fully filled in a centralized site. Therefore, the same number of RUs can be supported by a fewer number of centralized DUs.

To facilitate dynamic scheduling of computational and accelerator resources for VM DUs, an efficient topology reconfiguration approach for fiber interconnections is needed amongst DUs in the same rack, and among different racks of DUs. This requires a scalable and manageable optical flexibility point within the CO, and is located between the DU Mux and DU Baseband equipment, whether VM-based or traditional dedicated specific equipment based.



Remarks; EPC: Evolved Packet Core, MME: Mobility Management Entity, S-GW: Serving Gateway P-GW: PDN Gateway, DU: Digital Unit, RU Mux: Radio Unit Multiplex

The combination of an automated fiber switch product and DU equipment redundancy migration controller could provide a backup DU in a real-time way. The automated fiber switch fabric (e.g. Wave-2-Wave ROME500 product) is easily deployable without the need for engineering resources and expenses.

Finally, it is anticipated that the Evolved Packet Core (EPC) core network will migrate to the cloud as well, and the user plane of the EPC core network will use SDN-based switches and routers with extended functions. This SDN architecture approach coupled with an Automated Fiber Switch can enable MNO new business models transformation possibilities as the cloud concept can generate new business opportunities, such as DU equipment pool VM resource rental models, cellular infrastructure and intellectual property rental management agencies, and more premium mobile services.

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