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The Evolution of the Radio Access Network towards 6G

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The evolution of RAN

In this talk the technology evolution of RAN will be considered.

It will be shown that:

One of the main trends,
raising challenges
but opening opportunities
is virtualizing and opening the RAN,
i.e. implementing the concept of "Open RAN".

The idea of Open RAN is to make the RF subsystem and BB subsystem of cellular BSs independent.

Cellular Base Stations (BSs): the major components of a wireless infrastructure.

The BSc consist of:

A. Baseband (BB) part: a combination of digital hardware and software.

The BB functions include modulation/demodulation (bit-to-symbol mapping, IFFT/FFT), encoding and decoding; the MAC protocol, including radio scheduling; concatenation/segmentation of Radio Link Control (RLC) protocol; and encryption/decryption procedures of Packet Data Convergence Protocol (PDCP), for the downlink and uplink directions.

B. Radio Frequency (RF) part: analog RF hardware with a digital interface.

Cellular Base Stations (BSs): the major components of a wireless infrastructure.

For many years the BB part and the RF part have been tightly integrated…

BSs were entirely proprietary; all that was expected of a BS is to implement the 3GPP standards for cellular communication.

…around 2011 distributed BSs appeared.

A distributed base station consists of a Base Band Unit (BBU) and Remote Radio Units (RRUs) also called Remote Radio Head (RRH), connected to the BBU typically via a standard Common Public Radio Interface (CPRI).

- The RRH located close to the antenna in the cell site tower contained the radio functions.
- The BBU contained all baseband processing functions.

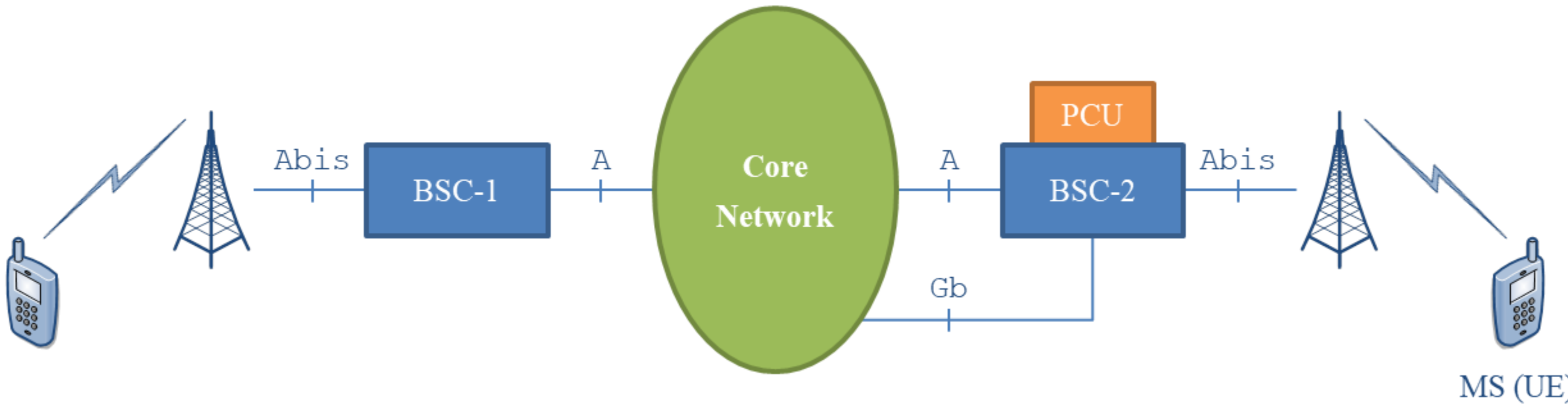
Cellular Base Stations (BSs): the major components of a wireless infrastructure.

- ✓ RRH and BBU are connected using a network segment called the Fronthaul network.
- ✓ The Fronthaul network is a point to point connection transmitting the radio signals using the CPRI.
- ✓ CPRI is the most common interface, but is essentially proprietary. Connecting the RRUs of one vendor to the BBU of another vendor is impossible due to the propriety of the solutions.
- ✓ Only large equipment manufacturers of BS, benefit from this network-building scheme, since this scheme does not allow changing the equipment manufacturer at the operator's discretion.

This is one major driving force for the evolution of the BS architecture over the last 5 - 10 years.

Another is the technology of Virtualization which has come to play a crucial role in the evolution of communication networks.

Architecture of RAN1 and RAN2 technologies



Base Station Subsystem (BSS) consists of the Base Transceiver Station (BTS), the Base Station Controller (BSC), the Air-interface, the Abis-interface and the A-interface.

BTS with its radio front-end realizes the direct wireless connection to Mobile Stations (MSs).

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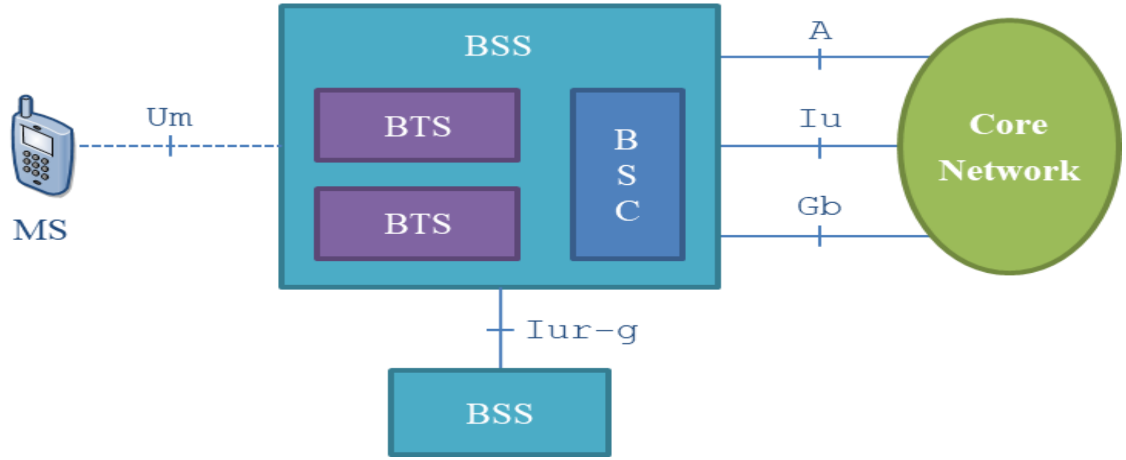
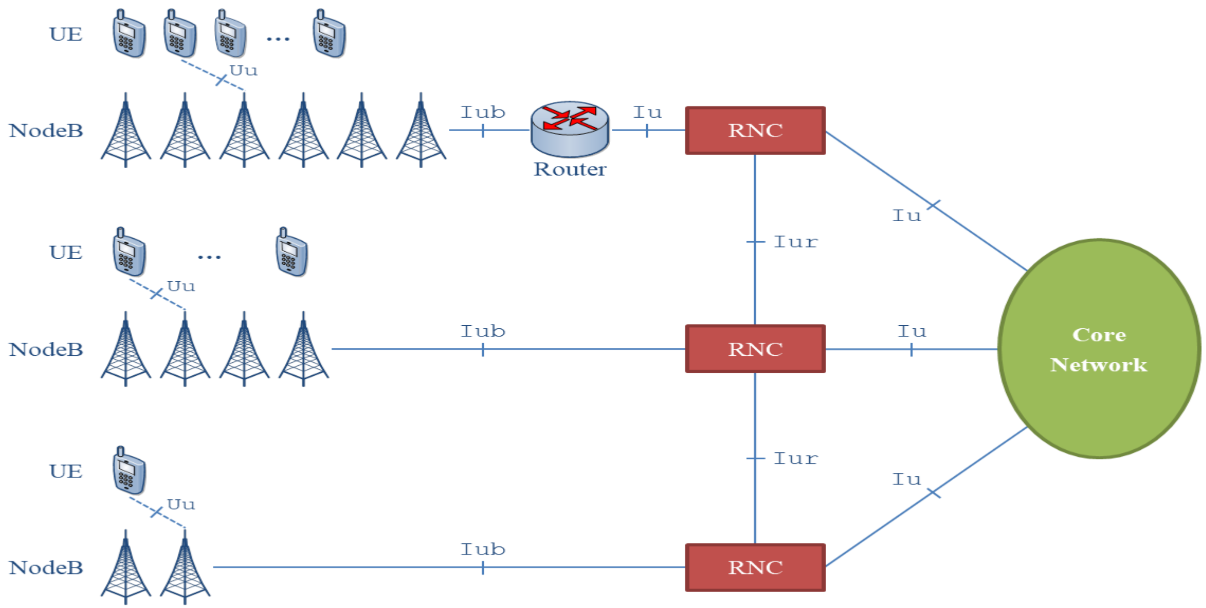
The GERAN architecture



The **GSM/Enhanced Data Rate for GSM Evolution (EDGE) RAN (GERAN)**, introduces significant modifications to the radio protocols in GSM/GPRS for the goal of throughput improvement and end-user quality of service (QoS).

GERAN specifies several new interfaces for connection with the core networks and RANs of other architectures.

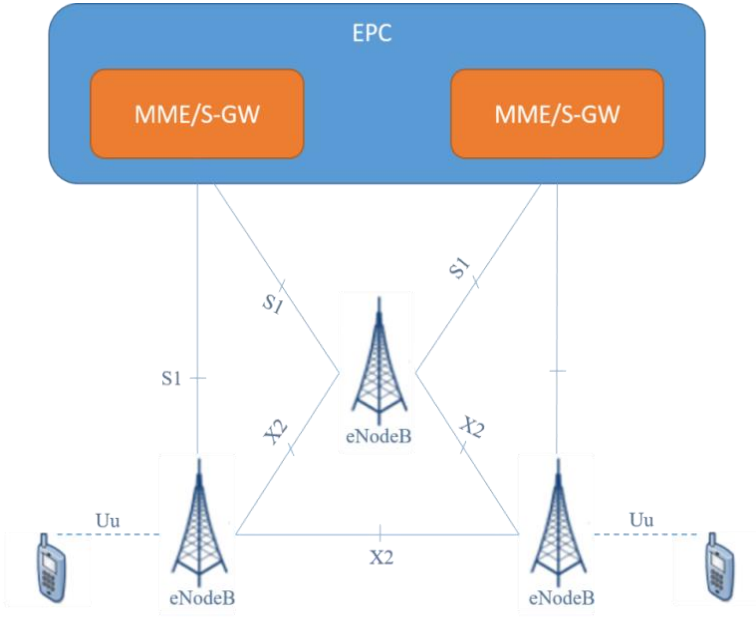
UTRAN architecture



To support simultaneously more user links (increased overall throughput), Wideband Code Division Multiple Access (WCDMA) was implemented in the *Uu* air interface of the **UMTS Terrestrial RAN (UTRAN).**

UMTS consists of Radio Network Subsystems (RNSs), each with one or more Radio Network Controllers (RNCs) (responsible for the mobility and resource management) and a number of BSs, each named a Node B.

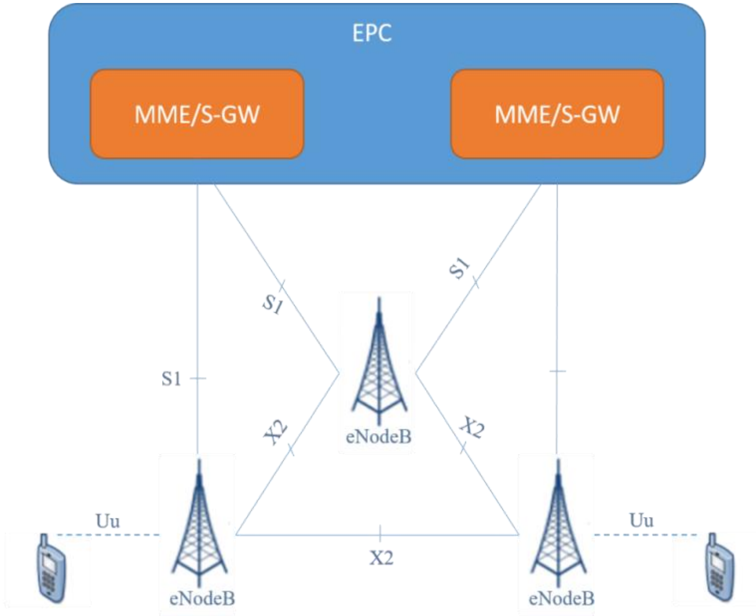
E-UTRAN architecture



Improved version of UTRAN with reduced latency and increased efficiency is the **Evolved UTRAN (E-UTRAN)**. Unlike former RANs, E-UTRAN integrates many functions such as RRM, header comparison, security, etc., into the eNodeB.

Such an approach enables load sharing and increases network reliability, eliminating the risk of single-point failure for the EPC nodes.

E-UTRAN architecture



User experience is improved implementing OFDM (for downlink) and SC-FDM (for uplink), carrier aggregation, enhanced Inter-Cell Interference Coordination (eICIC), etc.

Further improvements of the E-UTRAN were brought later by supporting services such as Narrow Band Internet of Things (NB-IoT), mMTC and D2D communications.

CLOUD-RADIO ACCESS NETWORKS

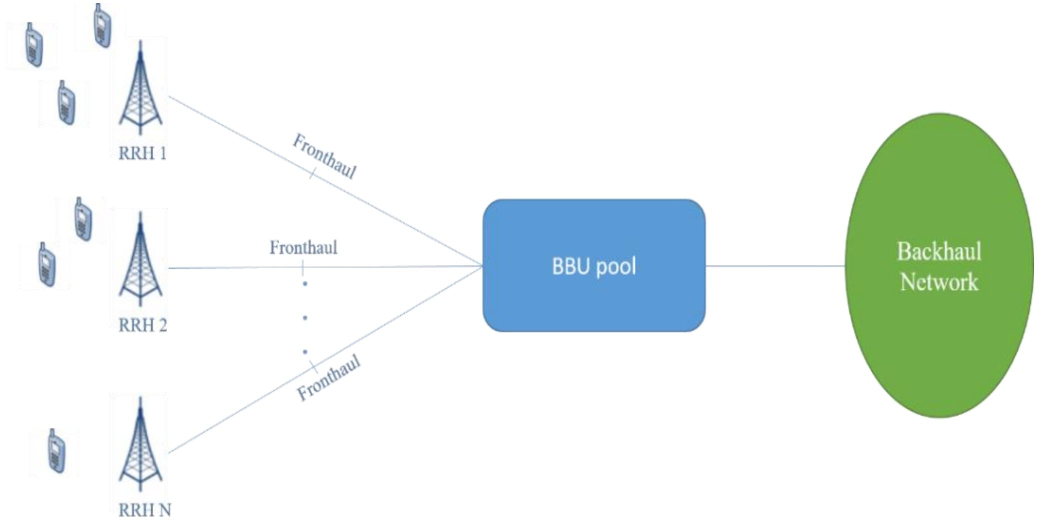
Cloud RAN (C-RAN) was initially proposed by IBM under the name Wireless Network Cloud (WNC), later described in details in a white paper of the China Mobile Research Institute.

C-RAN is has two main goals – to optimize network performance and to decrease the CAPEX and OPEX of mobile networks.

This is achieved through:

a) virtualization of the baseband processing;
b) centralization of management and control.

CLOUD-RADIO ACCESS NETWORKS

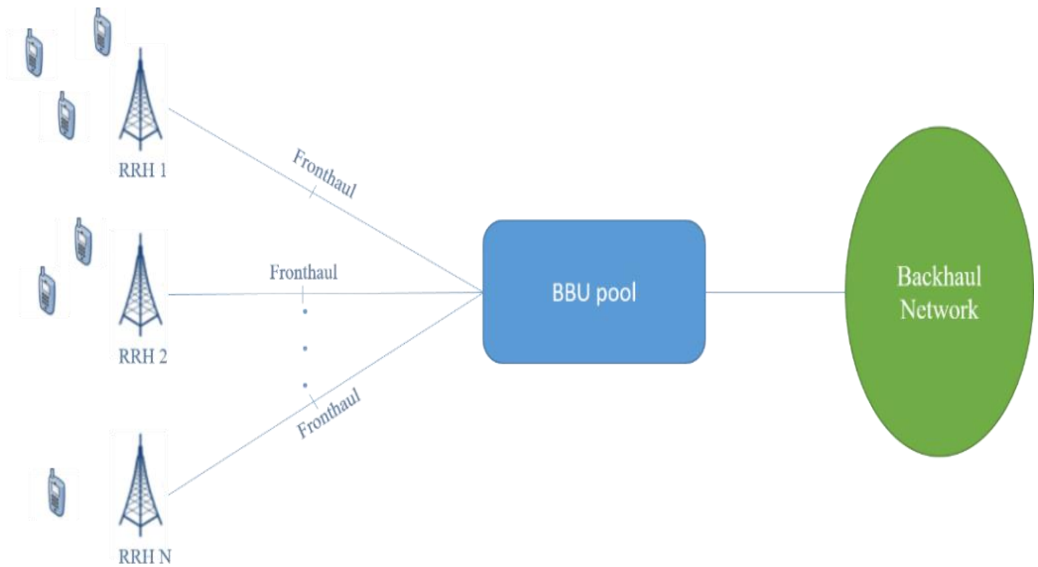


The main concept behind C-RAN is to separate all BBUs from their corresponding RRHs, and to pool them into a centralized, cloudified, shared, and virtualized BBU pool.

Every BBU pool is able to support up to tens of RRHs, and connected via a backhaul to the core network. In such a way cloud computing is embedded into the RAN architecture.

C-RAN, aims at implementing the whole base-band processing of radio signals in software, meeting strict latency requirements.

CLOUD-RADIO ACCESS NETWORKS



Embedding cloud computing into the RAN architecture allows:

- a) ***Commoditization and Softwarization***. This refers to software implementation of network functions on top of general purpose processors (GPPs) with no or little dependency on dedicated hardware.
- b) ***Virtualization and Cloudification.*** This refers to execution of network functions on top of virtualized (and shared) computing, storage, and networking resources controlled by a cloud operating system.

FOG RADIO ACCESS NETWORKS

One of the main issues with Cloud-RAN is the required bandwidth to transmit radio signals between the BBU- pool and each of the DUs.

Fog Computing is a new model for storing, processing, managing, analyzing data at the edge of the network called "Fog Computing" - meaning "fog is a cloud close to ground".

Fog Computing allows the implementation of a new RAN architecture called ***Fog RAN (F-RAN)***, in which processing, storage, communication, control and management functions are implemented at the edge of the cellular network thus aiming to take the advantages of both Fog Computing and C-RAN with the goal of coping with increasing traffic and providing better QoS to users.

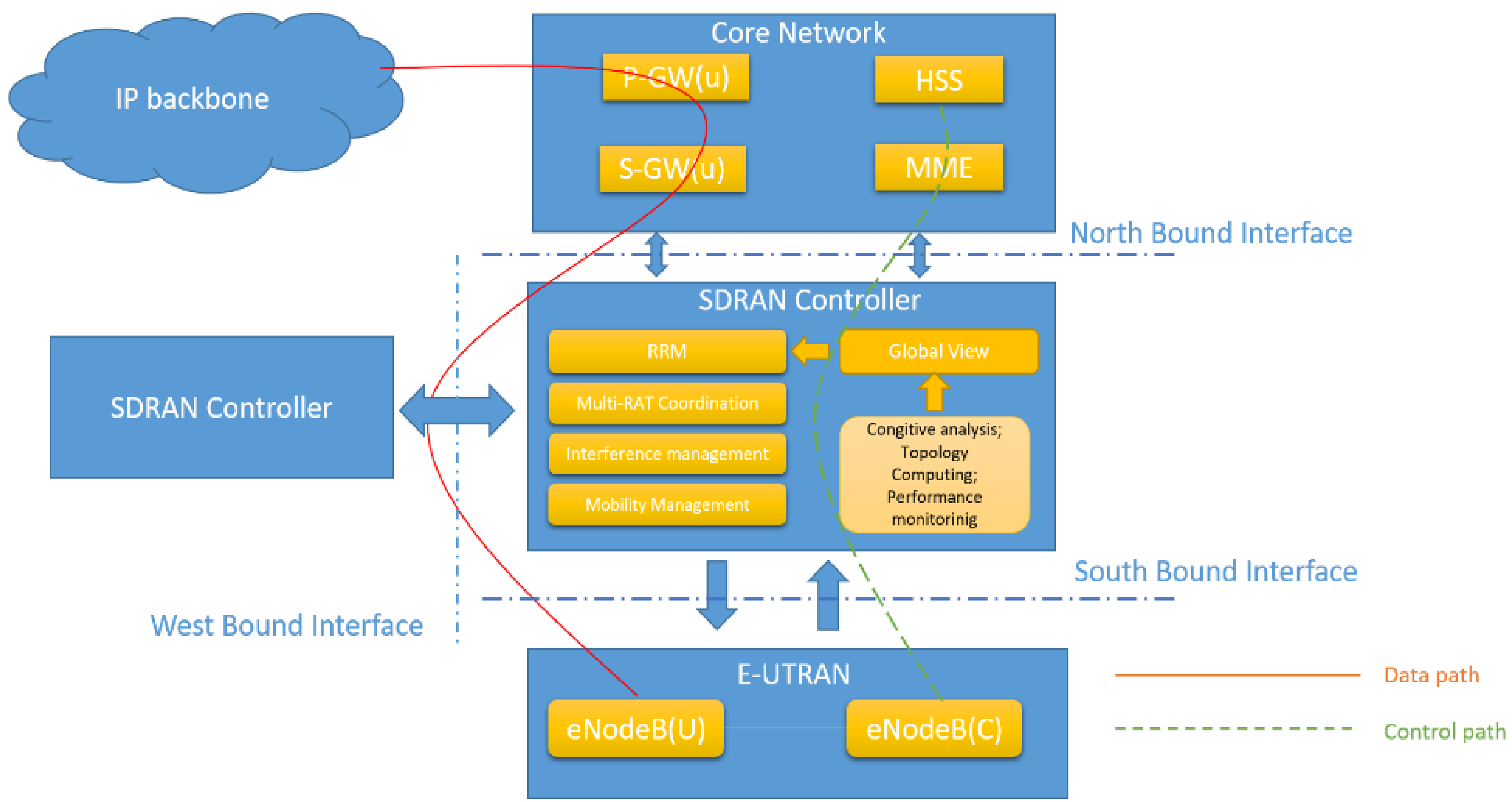
SOFWARE DEFINED RADIO ACCESS NETWORKS

SDN offers a logically centralized and flexible control model and the possibility of resource sharing that could be implemented in RAN.

A centralized C-RAN solution together with open platforms based on Software Defined Radio (SDR) can give the possibility of upgrading the RAN architecture.

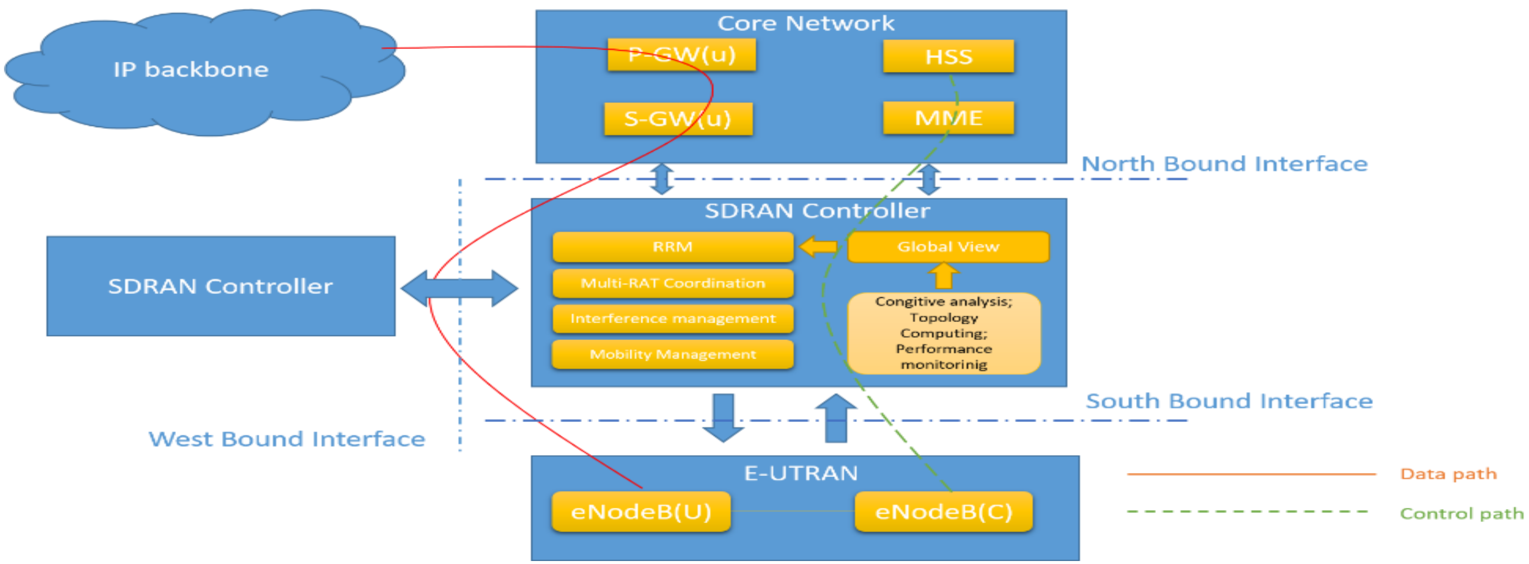
Such ***Software-Defined Radio Access Network (SD-RAN)*** architecture is considered as an effective approach to meet the diverse QoS requirements in the process of transformation of next generation RAN architectures in addition to the evolution of the air interface technologies.

SOFWARE DEFINED RADIO ACCESS NETWORKS



The SD-RAN could be considered as a C-RAN with complementary technologies such as CR, SDN, NFV, SON, Big Data analytics.

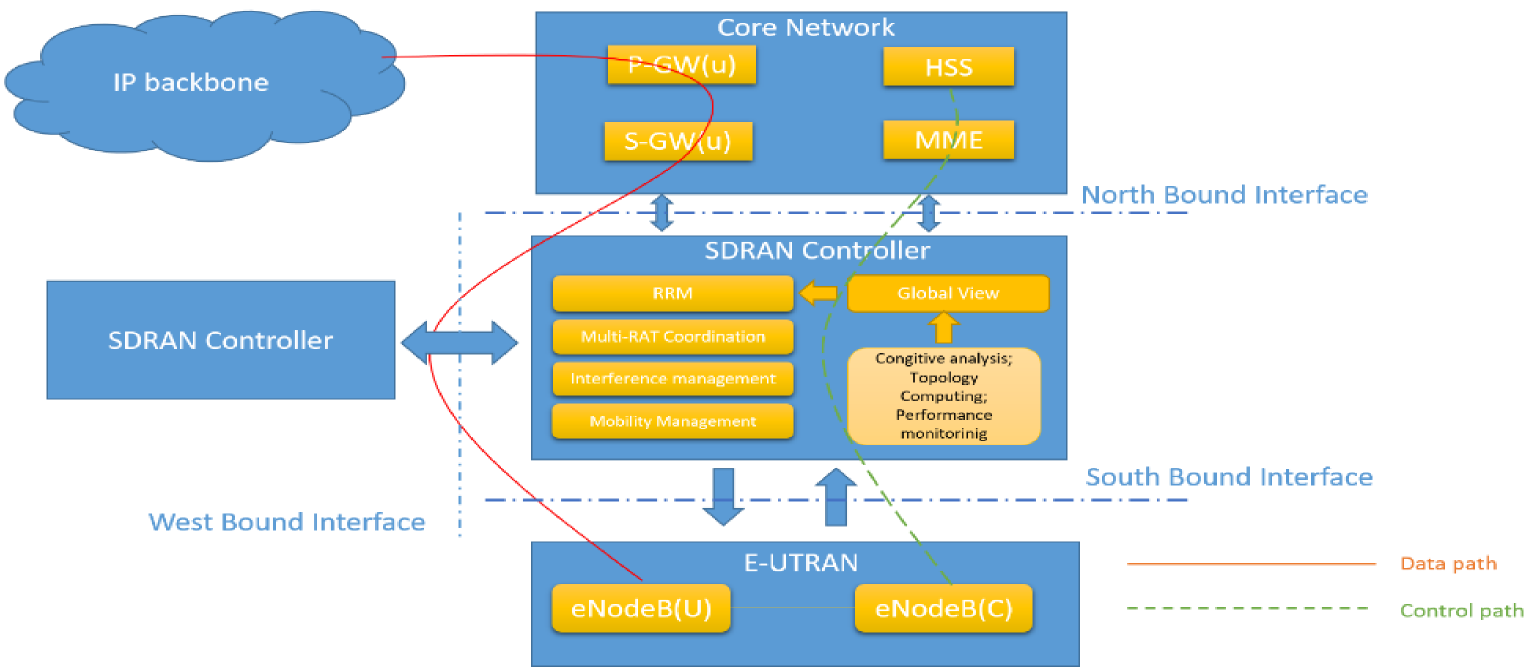
SOFWARE DEFINED RADIO ACCESS NETWORKS



In this architecture, the controllers could be logically divided into RAN controller and CN controller depending on the location of control entities.

The SD-RAN controller obtains the local view from eNode(C) and constructs the resource and network topology view from collected local views and UE profiles.

SOFWARE DEFINED RADIO ACCESS NETWORKS



Both C-RAN and SD-RAN have a centralized resource management.
In C-RAN, baseband data are collected by Fronthaul, while SD-RAN the controller implements centralized control functions.

Virtualized C-RAN and Virtual RAN

The deployment of NFV, SDN and SON in the C-RAN in order to virtualize all functions and resources in the RAN architecture forms a new type of C-RAN, called ***Virtualized-CRAN or V-CRAN*****.**

Virtual RAN or **vRAN** differs from traditional RAN in that it decouples the RRU from BBU on a GPPP. Virtualization of the RAN on GPPPs offers many benefits for RAN deployments such as more flexibility, faster upgrade cycles, resource pooling gains, and centralized scheduling.

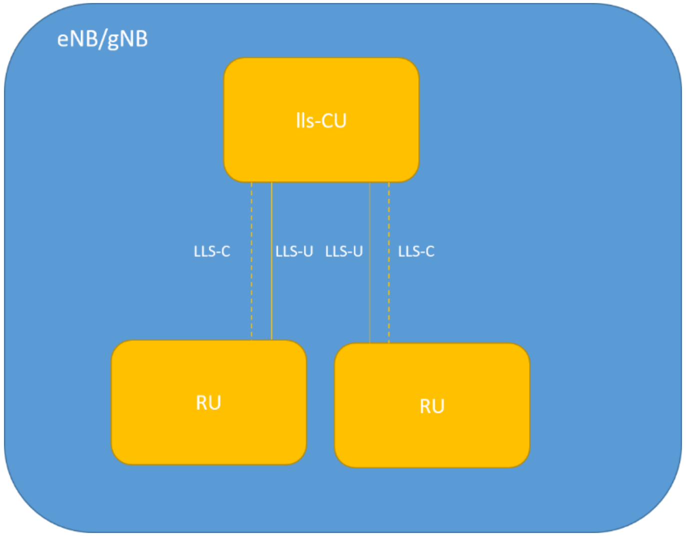
The xRAN Base Station Architecture

The goal of ***xRAN Forum*** is the standardization of traditional hardware-oriented RAN, focusing on three areas: separating the Control Plane RAN from User Plane, creating a modular evolved Node B (eNodeB) software stack using COTS hardware, and OIs.

xRAN fundamentally advances RAN architecture in three areas:

- decouples the RAN control plane from the user plane;
- builds a modular eNB software stack that operates on COTS hardware;
- publishes open north- and south-bound interfaces to the industry.

The xRAN Base Station Architecture



The architecture of the base stations eNb and gNb is divided into two types of nodes: lls-CU (Lower Layer Split Central Unit) and RU.

The LLS-C (Low-Layer Split Control-Plane) and LLS-U (Low-Layer Split User-Plane) interfaces are responsible for transmitting control-level (C-plane) and data-level (U-plane) messages in the LLS interface.

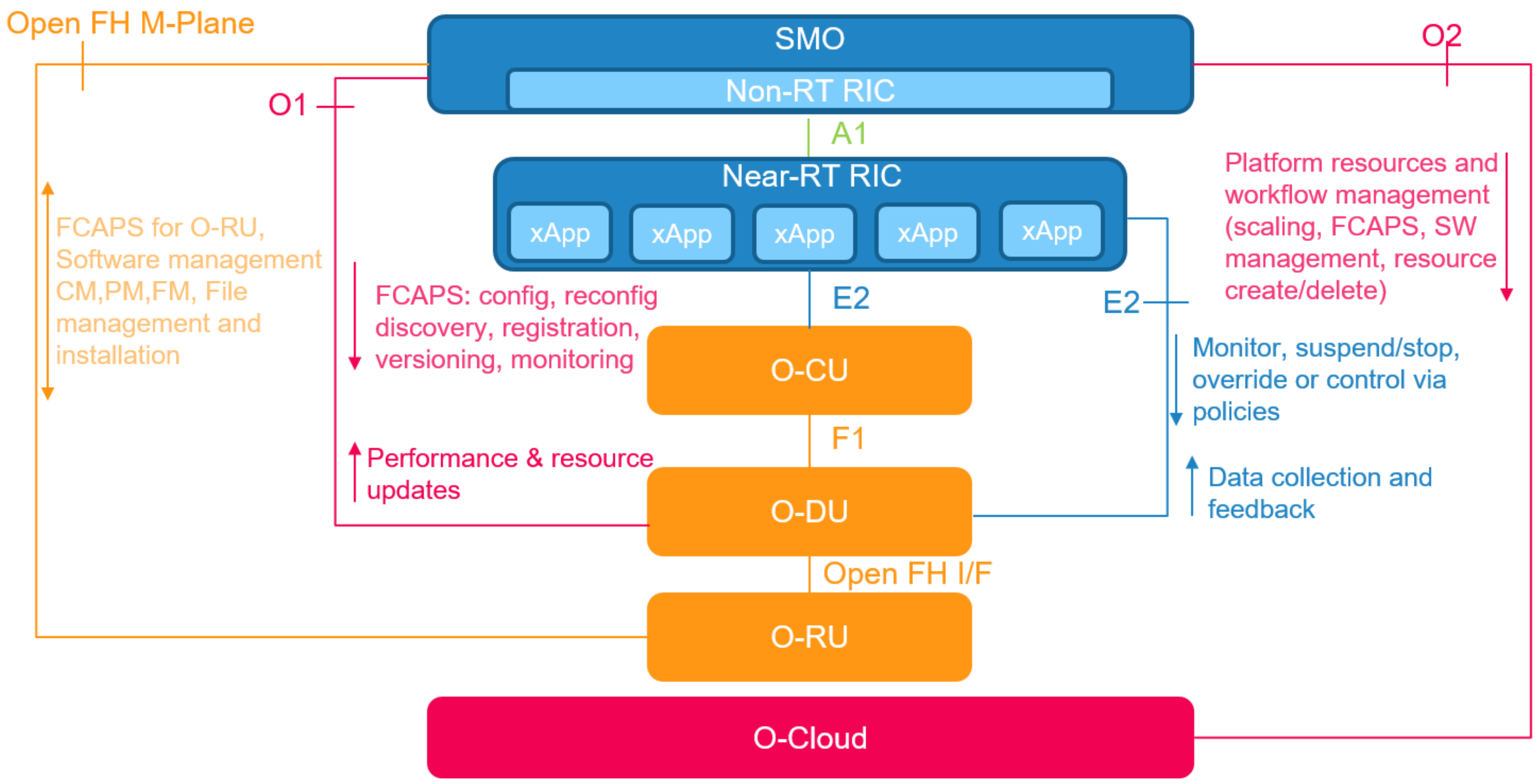
The O-RAN Architecture

The O-RAN Alliance is an industry consortium that promotes the definition of an open standard for the vRAN, with two main goals in the focus:

1) *Definition of an open architecture, enabled by well-defined interfaces between the different elements of the RAN.*
2) *Integration of machine learning and artificial intelligence techniques in the RAN, thanks to intelligent controllers deployed at the edge.*

All O-RAN components must expose the same APIs, which allows O-RAN-based 5G deployments to integrate elements from multiple vendors and to utilize COTS hardware.

O-RAN high-level architecture



Implementing intelligence in O-RAN

O-RAN is composed by by the eNBs and gNBs and a non-real-time and a near-real-time RAN Intelligent Controller (RIC).

The service management and orchestration (SMO) operates the non-real-time RIC, which performs control decisions with a granularity higher than one second.

The near-real-time RIC, performs a control loop with a much tighter timing requirement (as short as 10 ms), relying on different start, stop, override, or control primitives in the RAN, e.g., for radio resource management. Through the near-real-time RIC different processes could be controlled such as handovers, allocation of resources, load balancing, traffic steering, etc.

The near-real-time RIC can also leverage machine learning algorithms trained in the non-real-time RIC.

Open RAN Opportunities

The Open RAN concept is going to be a new wave in communications and will open up new doors for disrupting innovations and businesses.

Open RAN is a driver for not only for the development of new technical solutions but also new business models, that will reduce costs, increase business efficiency and enable greater innovation.

By disaggregating hardware and software components and leveraging open interfaces, this technology has the potential to enrich the mobile ecosystem with new technological solutions and business models.

Use Case Opportunities

Open RAN's flexible and open nature will foster the opportunities for realization of a rich set of new use cases.

Data analytics. Having access to the different types of open interfaces the collection of different types of data will be straightforward and easy. This will allow the implementation of a variety of data analytics approaches even at baseband level (IQ data) such as RF data analytics.

Context-based dynamic handover management for V2X. Open RAN's can exploit past navigation and radio statistics using Near-Real Time RIC's ML models to customize handover sequences on a User Equipment level.

UAV applications. *P*ossibility of the development of new UAV related applications such as dynamic adjustment of radio resource allocation policies to optimize jointly the service experience of the users and the mobility performance of UAVs.

Use Case Opportunities

QoE optimization. The main objective of such a use case is to exploit Machine Learning models implementing traffic classifiers, QoE predictors and QoS decision-making engines to optimize QoE of specific applications.

QoS based resource optimization. The ability to enforce fine-grained policies to drive QoS optimization in the RAN.

Traffic steering. The main goal is to exploit ML models to enable intelligent and proactive traffic steering control at UE granularity and in presence of multi-frequency cells.

Use Case Opportunities

- *Massive MIMO beamforming optimization*. The ability of configuring massive MIMO parameters will be paramount in future RANs.
- *RAN sharing*. RAN sharing support among different operators is one of the cornerstones of virtualized RANs.
- *Intelligent Processing Algorithms*. Open RAN is designed to make the radio access network more cost effective and flexible.
- *Edge computing based services*. The Open RAN has considerable potential to support future edge compute-enabled use cases .
- *Specific use cases*. The new Open RAN architecture, which is software-defined, unbundled, programmable, and flexible, can meet the requirements for enhanced mobile broadband and ultra-low latency.

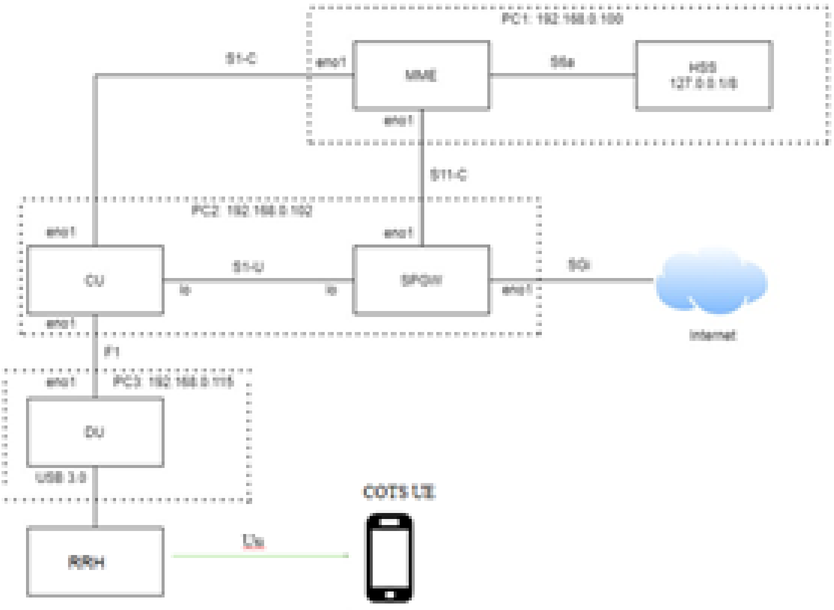
Implementation of Artificial Intelligence and Machine Learning

The integration of Artificial Intelligence/Machine Learning (AI/ML) is a cornerstone in the design of the O-RAN architecture.

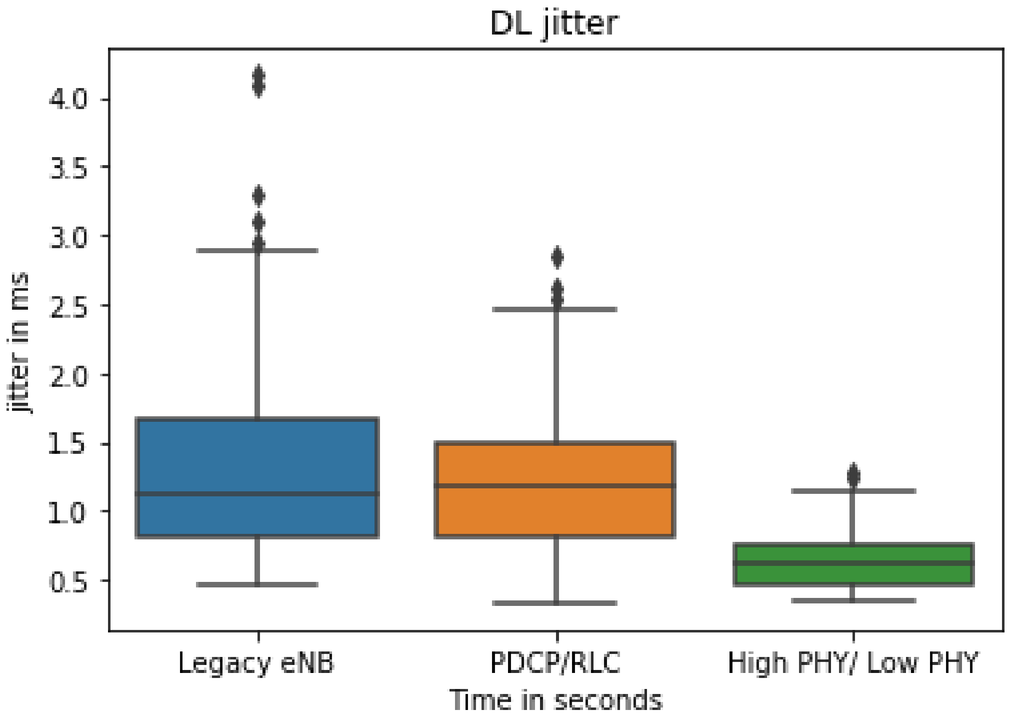
The O- RAN architecture aims to extend the SDN concept of decoupling the control plane from the user-plane in the RAN's, by fostering embedded intelligence.

The AI/ML integration represents a quite unique business opportunity. The goal is to exploit AI/ML models to carry out tasks that have traditionally been done quasi-statically by human operators in the past or are very complex tasks that never made the transfer from academia into business.

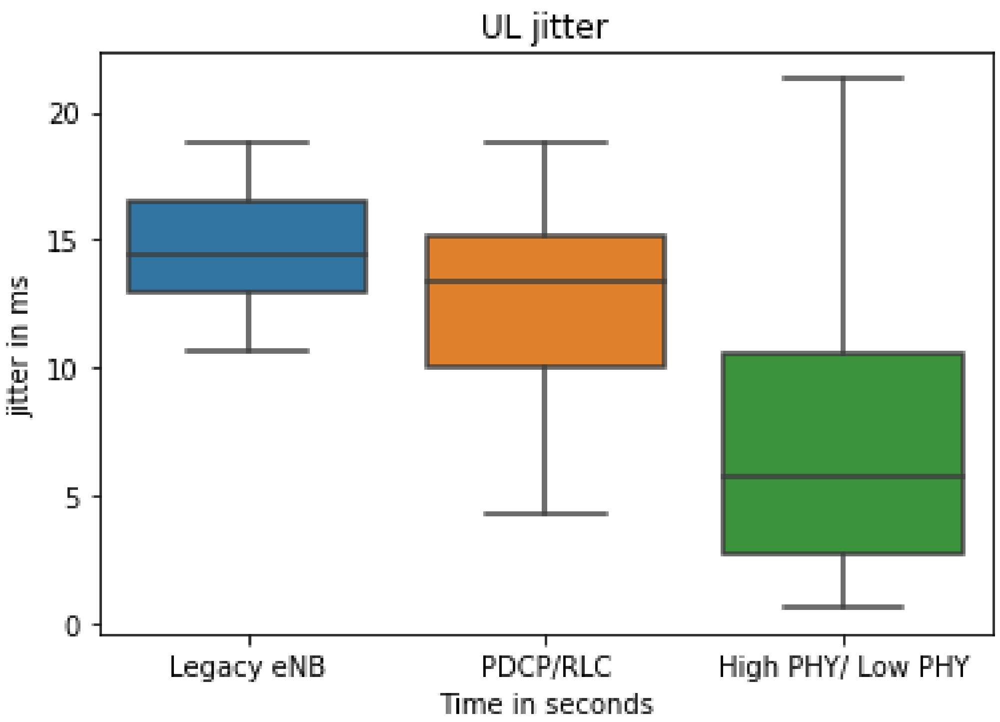
Some Experiment Results from an open RAN Testbed: The testbed configuration



Some Experiment Results from open an RAN Testbed: DL Delay Jitter



Some Experiment Results from open an RAN Testbed: UL Delay Jitter



Conclusion - 1

From the overview of RAN architectures there is an important thing that should be noted related to C-RAN. What could be seen is that there are different interpretations when discussing about C-RAN.

In most cases the issues of Centralized RAN, Centralized BBU, Cloud RAN and virtualized Cloud RAN, are considered all under the general topic of C-RAN.

From a business perspective they are similar, as all these approaches to C-RAN are intended to reduce CAPEX and OPEX for MNOs by centralizing and then virtualizing processing functions that were traditionally performed by dedicated networking equipment located at the antenna sites (cell sites), but from a technical point of view as could be seen from the analysis they are quite different.

Conclusion - 2

Considering the basic functionalities of the different RAN technologies, it is important to stress on the issue what is the difference between Open RAN, C-RAN and vRAN?

Generally, Open RAN can be considered as upgrade to vRAN, or as an evolution process.
Starting with C-RAN with the concentration and consolidation of the baseband functionality across a smaller number of sites across the network and cloud, followed by the vRAN where the baseband unit is virtualized, so that it is run as software on generic hardware platforms.

Finally, the Open RAN where the legacy, proprietary interfaces between the baseband unit (BBU) at the foot of the cell tower and the remote radio unit (RU) at the top of the tower are replaced with open standard interfaces.

Conclusion - 3

vRAN is not Open RAN as it is not completely open; it still contains proprietary interfaces and purpose-built hardware. The proprietary hardware remains as is, but the BBU gets replaced by a COTS server rather than proprietary hardware. The software that runs on the BBU is virtualized to run on any COTS server. The proprietary interfaces remain as they are.

The Open RAN vision is that the RAN is open within all aspects, with the interfaces and operating software separating the RAN control plane from the user plane, building a modular base station software stack that operates on COTS hardware, with open north- and south-bound interfaces.

This software enabled Open RAN network architecture enables “white box” RAN hardware – meaning that baseband units, radio units and remote radio heads can be assembled from any vendor and managed by Open RAN software to form a truly interoperable and open network.

Conclusion - 4

The traditional monolithic RAN solution approaches no longer meet today's quickly evolving network requirements.

Virtualized and Open RAN is a revolutionary, though complicated, technology that has all the characteristics to be disruptive.

The O-RAN vision will "*revolutionize not only the modus operandi and business of telecom operators, but also the world of researchers and practitioners that will be able to run a modern, open source, full-edged RAN control infrastructure in their lab and investigate, test and eventually deploy all sorts of algorithms (e.g., AI-inspired) for cellular networks at scale*"*.

**https://www.businesswire.com/news/home/20200605005027/en/Mavenir-Goodman-Networks-Partner-Deliver-OpenRAN-Solutions*

THANK YOU!