WHITE PAPER

Communications Service Providers
C-RAN

Towards 5G – RAN Virtualization Enabled by Intel and ASTRI*

ASTRI* has developed a flexible, scalable, and high-performance virtualized C-RAN solution to fulfill the demanding requirements of mobile network operators.

Overview

Cloud Radio Access Network (C-RAN) is a centralized, cloud-based new cellular network architecture that can be adopted by mobile network operators (MNOs) to improve the quality of service with reduced capital expenditure (CAPEX), operating expenditure (OPEX), and energy consumption. Radio Access Network (RAN) virtualization, a key architecture concept in 5G, provides the flexibility and scalability for MNOs to handle dynamic and challenging use cases, such as enhanced mobile broadband, massive connectivity, and ultra-reliable and low latency communications.

Hong Kong Applied Science and Technology Research Institute Company Limited (ASTRI)* has developed a flexible, scalable, and high-performance virtualized C-RAN solution to fulfill the demanding industrial requirements. ASTRI's C-RAN solution is based on Intel® general purpose processor (GPP) platform with a standard Functional Applicational Platform Interface (FAPI) specified in the Small Cell Forum, which can be easily integrated with the third-party protocol stack (PS) software. ASTRI's modular PHY processing architecture provides the flexibility to adopt different partitioning requirements for the base-band unit (BBU) pool and remote radio units (RRUs) depending on the deployment scenarios.

Challenges

Towards 5G, wireless broadband networks are expected to deliver more diverse and challenging services, such as enhanced mobile broadband operating at millimeter-wave frequency bands (28 GHz to 70 GHz) and mission critical communications with very low roundtrip latency in the range of within 1 ms. Moreover, MNOs are always looking for new applications, new services, and new system architecture to make their services more competitive. Network function virtualization (NFV) and cloud implementation of radio access network (RAN) are the key technologies demanded by MNOs. There are challenges to virtualize RAN components:

Higher throughput and low-latency requirements: The next-generation RAN will be in a distributed topology where the RRUs are located closer to the users serving higher rate, larger system bandwidth and low-latency traffics. The baseband RAN functionalities are implemented on general purpose processors (GPPs) where the system can dynamically pool and scale the computational resources to support these requirements. Dedicated hardware to accelerate signal processing is also considered in the design of BBU pool and RRUs.

Open and commercially available platform: MNOs are always looking for differentiations to bring in competitive advantages by integrating their own cutting edge services. The private network vendors are also looking for a programmable base station for their own specialized applications. Under the NFV framework, the

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RAN functionalities are virtualized into software components that could easily be modified and customized. The choice of general-purpose hardware allows MNOs to easily source the platform for resource pooling, resource sharing, power saving and easily integrating their own applications such as Multi-access Edge Computing (MEC).

ASTRI is working on different solutions in RAN virtualization. It offers commercial grade reference design on C-RAN BBU pool and RRUs based on general purpose hardware platforms. The design is highly flexible, scalable, and customizable for different applications in the next-generation wireless network.

Highlights of ASTRI's C-RAN Solution

ASTRI's C-RAN solution has the following features:

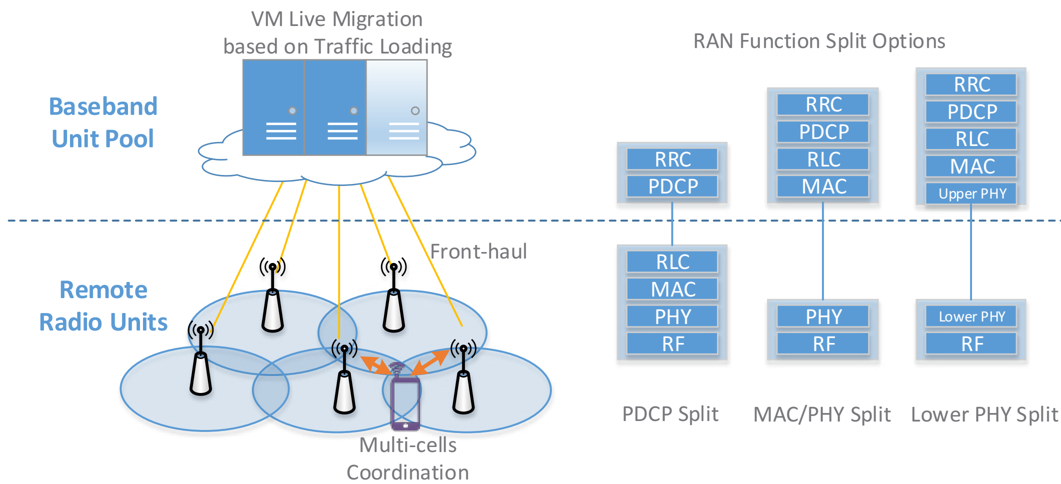

Figure 1. ASTRI's C-RAN Architecture

- **Flexible RAN Function Split**
Tasks partitioning between the BBU pool and RRUs in C-RAN determines the trade-off between enhancing cell coordination capability and reducing front-haul bandwidth and latency requirement. ASTRI's modular PHY processing architecture provides the flexibility to adopt different partitioning requirements.
  - The "PDCP Split" architecture relaxes the requirement on the front-haul bandwidth (e.g., 300 Mbps) and packet latency (e.g., ~10 ms). This architecture supports PDCP level of data plane aggregation of cells from different spectrum usages, such as LTE – WiFi Aggregation (LWA) for increasing the capacity using unlicensed spectrum.
  - The "MAC/PHY Split" architecture supports the multi-cells coordination in the MAC layer with small front-haul bandwidth requirement (e.g., 300 Mbps) and small packet latency requirement (e.g., ~0.1 ms). This architecture supports carrier aggregation and virtual cells. Some design partitioning the lower MAC (e.g., HARQ handling) in the RRUs could relax the latency requirement to milliseconds.
  - The "Lower PHY Split" architecture is the most flexible architecture, allowing MAC and PHY coordination among cells, but has the highest front-haul bandwidth requirement (e.g., 1 Gbps) and the smallest packet latency requirement (e.g., <0.1 ms). This architecture is highly suitable for indoor and high cell density deployments supporting Joint Transmission (JT) and Joint Reception (JR) for Coordinated Multipoint (CoMP), and could realize most of the challenging deployment scenarios in 5G such as massive MIMO and ultra-reliable and low-latency communications.

ASTRI's C-RAN architecture is based on standard FAPI, which can be easily integrated with commercial protocol stack (PS) software. FAPI is a standard MAC/PHY interface proposed by Small Cell Forum, which was adopted by most of the commercially available LTE base stations.

- **Multi-cells Coordination**
ASTRI's C-RAN provides centralized baseband processing capability and could realize the advanced multi-cell coordination algorithms in 4G and 5G wireless standards. These algorithms, such as JT and JR for CoMP, Inter-Cell-Interference (ICI) mitigation, virtual cells and massive antenna beam-forming, could significantly enhance spectral efficiency in the 4G and 5G heterogeneous networks.

- **RAN Virtualization and Virtual Machine Live Migration**
ASTRI's C-RAN solution supports RAN virtualization and dynamic computational resources allocation and migration. The processing entities for each cell are dynamically grouped and allocated to different virtual machines (VMs). During low traffic periods, the system can perform live migration of the processing entities and can shut down some of the processing cores for power saving or release them for other processing. The virtualized framework allows the freed-up processor cores to perform other virtualized applications, such as Multi-access Edge Computing (MEC) and other data center applications. The solution is designed to reduce energy consumption and increase hardware utilization of the computation units.

PHY, L1 adaptation layer, MAC, and RLC modules are implemented in the same compute node or a CPU hardware

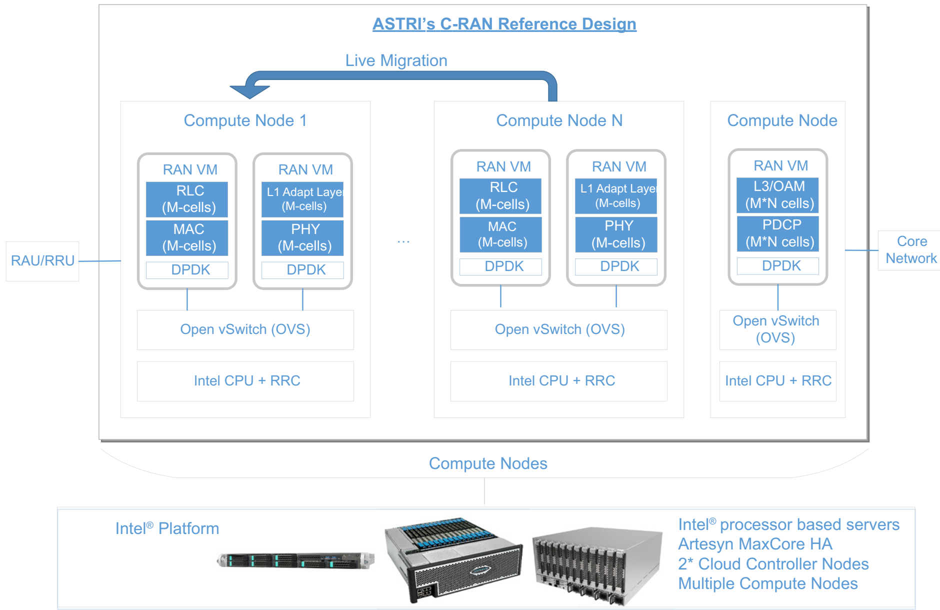

Figure 2. ASTRI's C-RAN Reference Design

to enhance data sharing and efficient processing. PHY implements the Physical Layer for multiple cells in LTE protocol network. L1 adaption layer handles the FAPI MAC/PHY interface message handling for multiple cells. MAC implements the Medium Access Control function for multiple cells and RLC implements the Radio Link Control function for multiple cells.

PDCP, L3, and OAM for all the cells are designed to run in one compute node or one CPU hardware to provide control plane handling as well as the control plane/data plane packet cyphering/integrity to all data from/to the backhaul. PDCP implements Packet Data Convergence Protocol function for all the cells. L3 implements Layer 3 functions of the base station, including Radio Resource Control (RRC), Radio Resource Management (RRM), and S1AP/X2AP. OAM is the Operational and Management module for all the cells.

Live migration of the VM (virtual machines) can be performed across compute nodes on demand, based on its loading, through the platform provided functionality, for example the live migration functionality provided by the Wind River* Titanium Server.*

- **VNF Reference Design using Intel® Platforms and Open Software Solutions**

To provide a foundation for rapid development of ASTRI's C-RAN solution, ASTRI joined the Intel® Network Builders ecosystem and leveraged the Intel Server Platforms and key communities delivering open source components for a reference architecture. The software stack includes many of the key open source elements needed to develop optimized NFV software applications. These key elements used in ASTRI's C-RAN reference design include Wind River* Linux,* Data Plane Development Kit (DPDK),* Open vSwitch (OVS),* OpenStack,* OpenDaylight,* and others. These elements are validated on a server platform that includes the latest Intel® Xeon® processor.

4G Virtual Cell

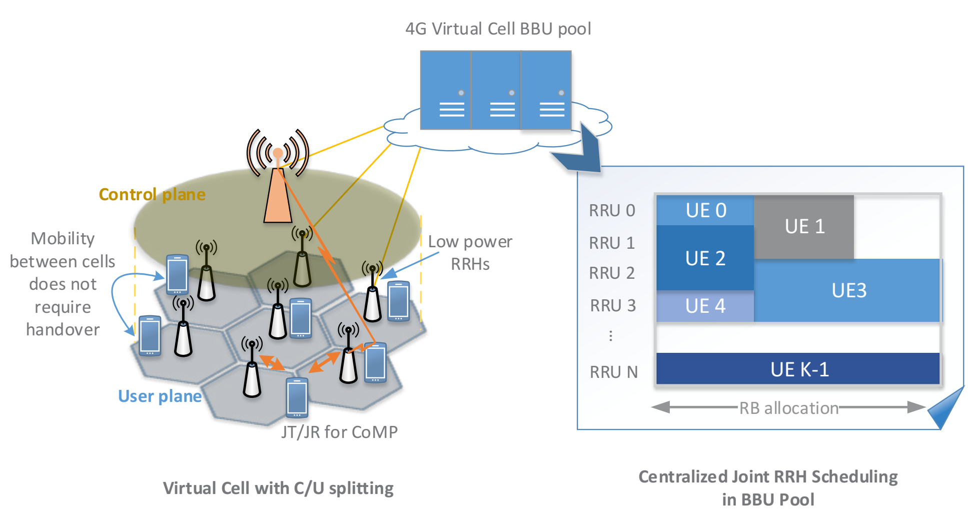

Figure 3. 4G Virtual Cell and joint scheduling in BBU pool

ASTRI's 4G virtual cell is a GPP-based C-RAN base station designed for providing high capacity, low power dissipation, and indoor and distributed 4G LTE coverage. The 4G virtual cell is connected to the mobile core network through fixed broadband and is connected to the RRUs through switched IP Ethernet front-haul network. Together with RAN virtualization technology, the distributed remote radio units are coordinated and virtualized into a single cell. The mobility of the user equipment (UE) is estimated and managed by the measurements (e.g., delay timing and power level) from each physical cell in the BBU pool. Therefore, no handover is required when the UEs are moving across the physical cells. Moreover, with the centralized cell coordination and interference control, the 4G virtual cell could support JT and JR for reliable communications and frequency reuse for enhancing the spectral efficiency. This system effectively makes operation and maintenance ("O&M") easier and reduces the deployment costs.

The high-level specification of ASTRI's 4G virtual cell BBU pool is shown in Table 1. ASTRI's commercial L1 reference design has been integrated and verified with the commercial protocol stack, an Intel® commercial grade NFV-based operating system (Wind River Titanium Server), a hardware platform from Artesyn,* and commercial RRUs based on small cell SoC.

FEATURES	ASTRI 4G VIRTUAL CELL BBU POOL
Server platform	Intel® architecture on Artesyn MaxCore* HA
OS/Virtualization	Wind River Linux with OpenStack High Availability VM live-migration
Remote Radio Unit	Small Cell RRUs with Ethernet front-haul
Application	4G virtual cell (96 sectors)
Standard	3GPP Rel-10
Bandwidth	5, 10, 15, 20 MHz
Duplexing	TDD & FDD in same code base
# of users	256 users per sector 16 UEs/TTI
Cell Size	10 - 100 km
Mobility	160 km/h - 500 km/h
Throughput	DL: 300 Mbps per sec UL: 150 Mbps per sector
UE support	Category 1, 2, 3, 4, 5, 6
Synchronization	GPS, 1588v2
Advanced features	Virtual Cell Joint transmission and Joint reception without antenna calibration

Table 1. ASTRI's 4G virtual cell features

5G Virtual Cell

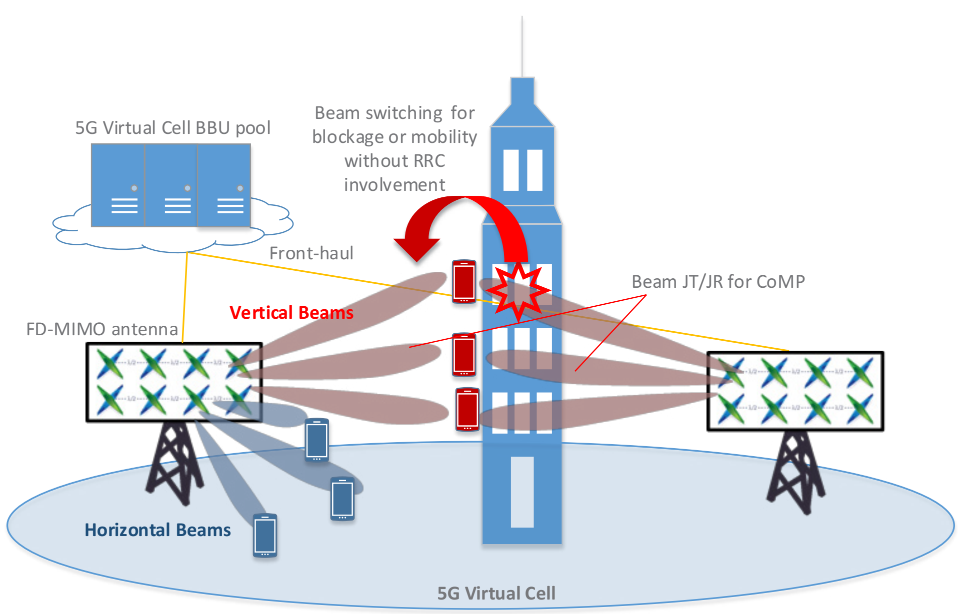

Figure 4. 5G Virtual Cell

The 5G virtual base station enhances the system capacity and spectral efficiency by aggregating a large BBU pool that can easily share the signaling among cells and Channel State Information (CSI) for active users. The centralized processing architecture allows easy implementation of control plane and data plane splitting (C/U splitting), JT and JR for CoMP, and inter-cell interference mitigation algorithms for the network densification.

Because of the software programmability and scalability of the BBU pool design, 5G virtual cell could easily implement the full-dimension MIMO (FD-MIMO) where the active antennas are placed in two-dimensional (2D) antenna array forming 3D spatial beams controlled by the centralized BBU pool. The beams are formed in both azimuth and elevation dimensions to provide highly concentrated energy to the desired UEs with least interference to others. 5G virtual cell also supports co-scheduled users in multi-user MIMO (MU-MIMO) operation to enhance the spectral reuse.

The centralized BBU pool could facilitate the beam management among cells that can form multiple beams from multiple RRUs to serve a target UE. A 5G virtual cell can be formed by multiple beams where UE mobility across different beams of an RRU or across RRUs can be tracked by the beam management procedure based on beamforming reference symbols and CSI feedback. The centralized BBU pools could simplify the UE mobility signaling and avoid the RRC involvement.

ASTRI's 5G virtual cell reference design supports

- New Radio (NR) baseband design in 3GPP (to be finalized)
- Massive MIMO Millimeter-Wave RF front-end processing
- NR cell covered by one or multiple RRUs with each RRU providing coverage through either single-beam or multiple-beams
- DL and UL beam management for initial access (e.g., beam sweeping) and beam fine tracking based on UE specific beam reference symbols
- Beam management without RRC involvement by synchronized RRUs linked via centralized baseband.

Conclusion

MNOs are building out their networks with challenging 5G requirements and demand on a new RAN architecture supporting high flexibility, high scalability, and high capacity. ASTRI, based on Intel® architecture, has developed a commercial grade virtualized C-RAN solution for 4G and 5G pushing the performance to the edge of the next generation network.