O-RAN TOWN: PILOTING A HIGH-POWER MULTIVENDOR OPEN RAN SOLUTION IN A BROWNFIELD NETWORK

A Whitepaper by Deutsche Telekom AG

Authors: Petr Lédl, Gerard Lyne, Claudio Coletti, Marc Fiedler, Andreas Schieder, Peter Stevens, Jörg Meyreis, Ondřej Choc, Friedbert Rich, Walter Grethe, Franz Seiser, Thomas Lips, Phil te Reh

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EXECUTIVE SUMMARY

With constantly growing traffic demands, the quality of the mobile connectivity provided to customers has never been more important. For Mobile Network Operators (MNOs) it is imperative to seek new approaches to continue delivering the highest network quality, performance and user experience in a TCO optimized way.

The industry generally agrees that today's traditional Radio Access Network (RAN) systems need to evolve. There is a lot of traction behind open RAN as the future approach to design and build high performance mobile networks that address our customers' essential need for connectivity.

Intuitively, the opening of the RAN to enable an intelligent and interoperable system makes a lot of sense. It will create a more robust ecosystem that offers MNOs more choice to mix and match components from different vendors, greater deployment automation and flexibility, as well as opportunities to increase service innovation.

Deutsche Telekom has been at the forefront of the open RAN movement, starting with the co-founding of the XRAN Forum and then co-founding the O-RAN ALLIANCE to drive the open RAN architecture and specify interoperable element interfaces required to speed up the process to deliver innovative capabilities.

Open RAN has made great progress since then and continues to mature, but the overall design also comes with its own complexities. To have the greatest impact on open RAN solution development, Deutsche Telekom is prioritizing the development of multi-vendor open RAN for a scaled, high-performance deployment in a brownfield operator network environment.

To assess the technology, deployment, and operational challenges, we piloted a multi-vendor open RAN solution in our live environment in Germany. The pilot, which we named O-RAN Town, was established in Neubrandenburg, Germany with funding from the Federal ministry for Digital and Transport (BMDV). This funding was part of an initiative to strengthen research, development and innovation activities in the field of open RAN through lighthouse projects. In June 2021, the first site went live at O-RAN Town in Neubrandenburg, Germany, providing 5G services with massive MIMO integrated into the live network.

Whilst the technology gap between traditional S-RAN and open RAN has narrowed; our findings show that development work is still required to ensure open RAN solutions reach full performance and maturity parity. And by leveraging advancements in cloud and silicon technologies, it is our ambition for open RAN to eventually outperform state of the art S-RAN solutions in terms of performance as well as deployment and operational efficiency.

This white paper presents our key learnings gained from the O-RAN Town project:

Technology Readiness: The O-RAN Town pilot was initiated in order to assess open RAN technology readiness for a large-scale, high-performance macro deployment use case. The multi-vendor integration and operation of NEC massive MIMO Open Radio Unit (O-RU) and Fujitsu classical 4x4 O-RUs with Mavenir virtualized baseband processing was achieved. While we observed encouraging development in open RAN technology within the wider industry ecosystem, we concluded however that the current open RAN readiness vis-a-vis all Deutsche Telekom architectural and performance requirements does not yet allow for immediate large-scale deployment. Based on our experience gained, we expect however that a smaller scale multivendor open fronthaul based deployment capable of supporting all Deutsche Telekom services is realistic by the end of 2023. With that knowledge, our main focus for the current phase of development work is now on multi-vendor massive MIMO performance optimization, power efficiency enhancements and automation development for virtualized baseband deployments among other aspects.

Integration complexity: As the open RAN ecosystem is still in an early stage, the integration effort required at O-RAN Town was quite high and we took on a very active role in the integration activity. With the combined experience of RAN solution integration and Service Management and Orchestration (SMO) integration, we are aiming to build the know-how and expertise on open RAN end-to-end solution integration. This is a necessary step for an MNO to build up the capability to take control of the open RAN solution. Tight alignment between all system components vendors (e.g. Open Central Unit / Open Distributed Unit vendor, O-RU vendor, O-Cloud hardware and software vendors) and Deutsche Telekom is required to ensure interoperability and alignment on all technical requirements. Applying an agile approach with fast delivery of necessary software adaptations is essential to ensure proper system integration. A consistent approach is required across all RAN components with strong adherence to maintaining the verified solution. Small inconsistencies could severely impact on RAN stability and performance. We anticipate that for future deployments, it will also be possible to rely on pre-integrated equipment combinations that leverage certification and badging frameworks. This will contribute to an increasing integration efficiency in the open RAN ecosystem.

Deployment and Operational Experience: Solution development, deployment and operation in an open RAN ecosystem requires flexibility and agreed support processes between the involved parties. The main issues we encountered were related to software functionality, system stability and performance. Solving these issues required a lot of patches, software updates and consequently testing in the lab environment. We developed extensive test scenarios and procedures as well as test automation capabilities to ensure efficient validation of open RAN solutions. All our open RAN suppliers will be tested against that framework. As open RAN is generally a new technology, some parts of the solution can have limited availability or maturity. For example, support for required tracing and observation functions. To ensure minimized reaction and fault recovery times in a best-of-breed open RAN solution deployed and operated at scale, it will be essential that effective fault recovery and troubleshooting processes leverage tools adapted for a multi-vendor environment.

The results and experience gained during the O-RAN Town trial deployment reaffirm our commitment at Deutsche Telekom to make open RAN the technology of choice for future networks - and bring its benefits to our customers across Europe. The learnings from O-RAN Town have helped to shape our contribution to the activities of the open RAN MoU group of European operators, who are advancing various aspects of the open RAN ecosystem through a set of actions, topics spanning from maturity to security and energy efficiency. Last but not least, it has informed our requirement setting and decision making as we prepare for the next stage of our open RAN journey at Deutsche Telekom.

1 OPERATOR DEMAND FOR DISAGGREGATED RAN

5G is expected to bring an exponential increase in wireless traffic and diverging services requirements. Operators have to build out scalable, flexible, and cost-efficient mobile networks to continue to deliver the highest network quality, performance and user experience to their customers. The RAN is an essential part of any high-performance mobile network that scales operationally to support high quality, reliable nationwide services. The RAN provides access to and coordinates the resources across the radio sites in a mobile network.

While 3G is being phased out, 2G, 4G and 5G still need to be supported by today's RAN technologies - at least in Europe. Due to the always increasing capacity demands, every generation of mobile networks has brought additional spectrum requirements. This has resulted in a diverse spectrum holding of low bands (e.g. 700, 800, 900MHz bands), mid bands (e.g. 1500, 1800, 2100, 2600MHz bands) and high bands (e.g. 3.XGHz) that mobile network operators are using today in their networks. Many or sometimes all of them are deployed on a single cell site.

On the implementation side, highly sophisticated RAN systems combining 2G, 4G and 5G standards have increased the demand for more efficient and optimized baseband processing. Driven largely by these requirements, RAN vendors adopted a proprietary and siloed (vendor locked) model for system design and implementation characterized by dedicated hardware with tightly integrated software. This has led to the current ecosystem challenge - in which relatively few global RAN vendors remain and high entry barriers are preventing the emergence of alternative suppliers to provide RAN solutions relevant for large scale mobile network deployments.

Moreover, based on a combination of purpose-built hardware and tightly integrated software, it has become a very costly and cumbersome process to modernize, innovate and evolve RAN infrastructure. Overall, the RAN component is the biggest cost block in the Total Cost of Ownership (TCO) of a mobile network.

The industry generally agrees that the RAN needs to evolve towards a disaggregated/modularized, more software-driven, virtualized model that will allow operators more flexibility and agility to deploy and operate mobile networks.

The most important enabler for ecosystem diversification is further disaggregation of RAN architecture. A system disaggregation model requires well-defined and open interoperable interfaces which allow different sub-system vendors to integrate and interoperate with the various sub-system parts that make up a RAN system. The O-RAN ALLIANCE – a worldwide, carrier-led organization founded in 2018 – lays the standardization groundwork for re-shaping the RAN industry towards more open, virtualized, intelligent and fully interoperable mobile networks.

The logical architecture for disaggregated RAN, which complements and extends the reference RAN architecture standardized by 3GPP, is depicted in the figure below:

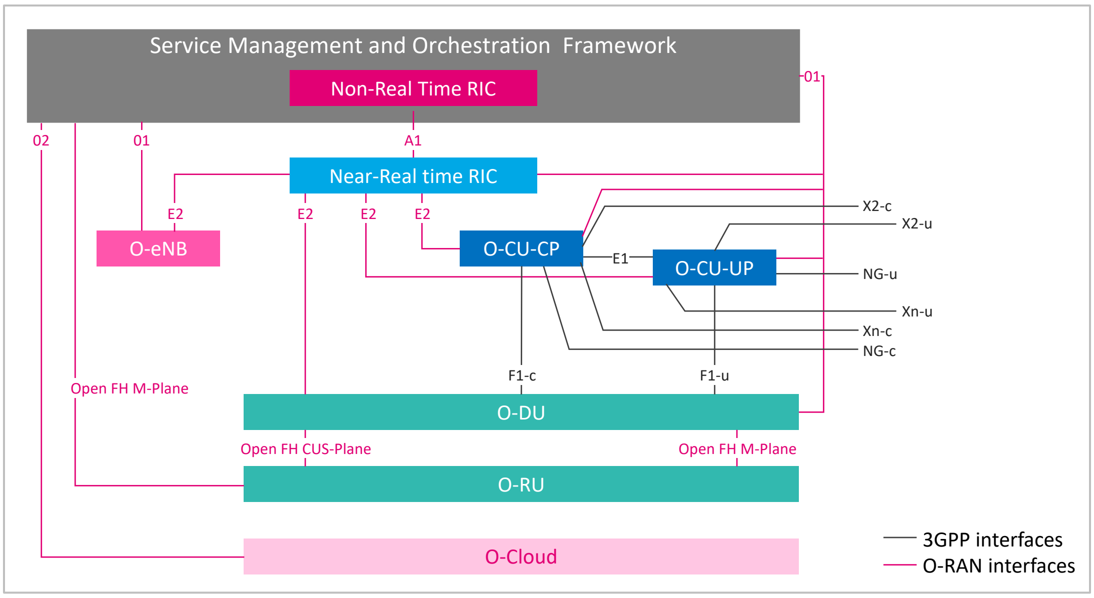

Figure 1: Disaggregated RAN architecture

The transformation of RAN by open RAN is driven in three main technical areas around openness, virtualization and intelligence:

1. Open interfaces to realize interoperability

Open fronthaul (OFH) is the key interface to implement and enable RAN disaggregation. The OFH interface decouples the Open Radio Unit (O-RU) from the Open Distributed Unit (O-DU) baseband functions. The O-RAN Alliance also specifies profiles for 3GPP RAN interfaces to achieve interoperability (IOT) among different vendors (e.g., X2 interface).

2. Open RAN cloudification and orchestration enabling virtualized RAN

Fast evolution and availability of highly efficient General-Purpose Processor (GPP) based Commercial Off-The-Shelf (COTS) hardware has already led operators to migrate functions in the core network and other domains to the cloud.

This trend is now moving to RAN. The O-Cloud approach is enabling RAN hardware and software disaggregation and allows operators to use COTS hardware for baseband workload processing.

All RAN nodes and the underlying cloud computing layer (O-Cloud), which enables virtualized deployment of network functions (vRAN), are managed and orchestrated by the Service and Management Orchestration (SMO) framework via the OFH M-Plane, O1 and O2 interfaces, respectively.

3. Intelligence driving optimization and automation of RAN operations.

The RAN Intelligent Controller (RIC) is a key technology to provide intelligent radio resource management and optimization by using the AI/ML models. RIC includes two layers.

- The Near-Real Time Radio Intelligent Controller (Near-RT RIC) with a control frequency below 1 second. Near-RT RIC should bring enhancements in terms of intelligence and programmability via the E2 interface.
- The non-real-time (non-RT) RIC with a control frequency over 1 second. The non-RT RIC, which is hosted by the SMO, supports non-real-time radio resource management via RAN policy optimization (A1 interface) and AI/ML capabilities.

Ecosystem impact of open RAN and operator benefit

The expectation from open RAN in the long term is to foster a robust and vibrant ecosystem of RAN solutions. This gives operators more options to mix and match components for a particular use case or deployment scenario, flexibility to introduce new features for service innovation as well as allowing a faster time-to-market. In the mid-term, it is expected that disaggregated RAN solutions will provide a TCO advantage over classical integrated solutions.

Disaggregation is not only a different approach to solution development, but also a transformation force impacting roles and responsibilities along the complete technology lifecycle. Managing the lifecycle of a new open RAN solution that leverages a multivendor ecosystem requires a focus on two integration areas. The vertical integration area comprises of the COTS hardware, the virtualization technologies and RAN software stack integration. The horizontal integration area includes the RAN virtualized O-BBU and O-RU integration.

Close cooperation between operators and partners

Open RAN and ecosystem diversification provides a lot of opportunities. However, it is also significantly increasing complexity due to the multi-vendor approach. Collaboration between operators and partners will be key to ensuring the success of open RAN deployments. A lot of preliminary coordination is required between all involved parties, including alignment on the open fronthaul interoperability (IOT) profiles, the deployment and integration considerations for the O-Cloud HW layer, O-Cloud SW and CNF layer as well as RAN infrastructure integration into the SMO. More details are provided in Chapter 3.

It is apparent that the requirement to manage these many permutations increases the complexity compared to the current system of SRAN deployment. To handle integration complexity and related costs, alignment in a wider industry community is required to reduce or avoid duplication of effort. For example, tasks like interoperability testing related to common operator requirements should happen ideally once and get shared amongst operators. This demands a supporting certification and badging framework to confirm interoperability. The O-RAN ALLIANCE and Telecom Infrastructure Project (TIP) are the main industry bodies working on this approach.

Automation is essential

Moreover, there is also a complexity challenge in disaggregated solutions to ensure cost efficient integration for optimized performance. Automation is required to manage complexities across all lifecycle management (LCM) disciplines such as testing, deployment and operation. The SMO will enable operators to orchestrate and automate elements from multiple different vendors in a disaggregated system.

2 DEUTSCHE TELEKOM'S OPEN RAN SOLUTION APPROACH

For its broader technology transformation, Deutsche Telekom's is implementing a Telco-as-a-Platform approach as the common future digital production model. Disaggregation is a key component of this transformation strategy. In this approach to RAN disaggregation, we prioritize the development of an open RAN solution as a deployable option for a large scale, high-power and performance macro layer RAN. For Deutsche Telekom, as a leading network provider, a deployable open -RAN solution needs to be on par with, or better than, existing SRAN based solutions in terms of network capabilities and performance. Deutsche Telekom's RAN architecture and priorities are described in this section.

2.1 OPEN FRONTHAUL

In the traditional monolithic RAN solutions, the fronthaul interface connecting the 3GPP signal processing DU function to the RU is referred to as the Common Public Radio Interface (CPRI). The adoption of higher bandwidth and massive MIMO (mMIMO) has led to the definition of a more efficient enhanced-CPRI (eCPRI) interface with more functional splits to reduce the overall fronthaul bandwidth requirements. The main drawback of CPRI or e-CPRI interface specifications is that they were not defined as an open and interoperable interface, so the DU and RU must come from the same supplier. In contrast, the open fronthaul interface enables the O-DU and O-RU to be sourced from different vendors (as defined by O-RAN ALLIANCE and described on Fig. 2 - illustrating the logical split within the physical layer for two modes, denoted as O-RU, Category A' and Category B').

An important pre-requisite for open fronthaul based solution adoption and commercial deployment is to bring performance and capabilities on a par with integrated solutions. Therefore, a disaggregated solution must be capable of supporting wide bandwidth, multi-band and high output power requirements, power consumption requirements as well as functional requirements like CA, network sharing, dynamic spectrum sharing (DSS) among others.

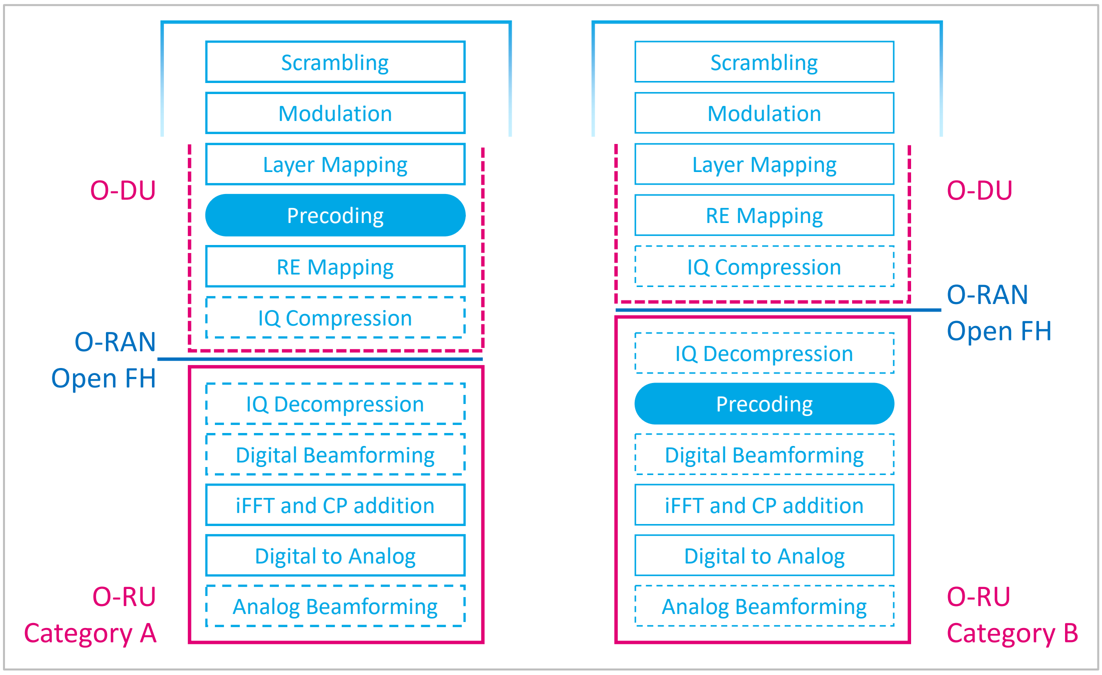

Figure 2: Logical Split: O-RU Category A (precoding in radio is not supported) and O-RU Category B (precoding in radio is supported) O-RAN Radio Units

2.2 HARDWARE/SOFTWARE DECOUPLING FOR VIRTUALIZED BBU

A key aspect of the open RAN vision is the opportunity to maximize the use of COTS server hardware to host the virtualized baseband unit functions. Ideally, the open RAN software should be deployable on performant hardware from any supplier – as it is not tightly coupled to any specific hardware. However, at the time of this trial commercially available open RAN solutions remain highly dependent on the chosen hardware. The main reason is that hardware optimization is required to meet high performance criteria with an acceptable power efficiency (i.e., HW acceleration (ACC) is still required for highly compute-intensive tasks). Multiple acceleration solutions approaches are emerging, and we believe that open RAN SW vendors will adopt larger portfolio of acceleration options to provide required flexibility.

As a key enabler of open RAN adoption, Deutsche Telekom wants to see more hardware advancements in the ecosystem so that more options and choice emerge from diverse sources. Operators must have the option to choose the Central Processing Unit (CPU) architecture used for their open RAN hardware, as well as the hardware acceleration used to offload computationally intensive functionality. For the latter aspect, a detailing of the O-RAN ALLIANCE concept of the Acceleration Abstraction Layer (AAL) is an architectural starting point. This concept will enable the option to introduce new software vendors on a unified hardware and CaaS layer platform.

Although Deutsche Telekom targets virtualized solutions for the O-RAN BBU, a monolithic physical network function (PNF) deployment for BBU functions can still be considered for an early distributed deployment scenario.

One of the main benefits of a virtualized system is the capability to enable highly automated RAN planning, deployment, and operations tasks. A fully virtualized system supports life cycle management of the decoupled hardware and software elements, the entire FCAPS (Fault, Configuration, Accounting, Performance and Security) operations and the ability to introduce new software vendors on a unified hardware and CaaS layer platform.

However, these capabilities will only emerge over time. Main items missing are:

- O2 interface maturity for Kubernetes (K8s) workloads
- Unified Helm charts / standardized data models
- Aligned A1 standardization methods of Near-RT RIC or O-CU/O-DU (if Near-RT RIC is not deployed as separate function) vendors to allow “easy” integration for Non-RT RIC optimization and the usage of rApps (e.g. Config Management / Metrics notifications)

2.3 AUTOMATION: INDEPENDENT SMO FRAMEWORK

A key part of Deutsche Telekom’s open RAN approach is to introduce a vendor independent Service Management and Orchestration (SMO) framework. The SMO is at the heart of the complete lifecycle management of all open RAN components in the deployment for managing the RAN disaggregation complexity. It provides the necessary control and flexibility to adapt RAN infrastructure according to current needs, such as easier RAN software vendor swaps, as well as the opportunity to differentiate by introducing innovation. In concrete terms, this means that software upgrades can be tailored to specific situations and rolled out much faster. In addition, new functionalities can be tested more quickly and ultimately made available to customers much sooner.

Deutsche Telekom examined both proprietary and open-source solutions, before choosing the open-source Open Networking Automation Platform (ONAP) to automate the O-RAN Town related services. An advantage of ONAP is that it can be used as a platform in multiple network domains.

The O-RAN ALLIANCE has defined the architecture and functional scope of a SMO framework. Based on that architecture Deutsche Telekom defined the functional split and usage of ONAP components to build a vendor independent Deutsche Telekom SMO platform that helps us achieve the benefits of the disaggregation. The deployment of the ONAP-based SMO at O-RAN Town is detailed in chapter 4.

2.4 DEPLOYMENT ASPECTS

Based on the above considerations, different scenarios have been identified for open RAN deployment ranging from distributed architecture to fully centralized:

- Distributed RAN: the BBU functions are co-located with the O-RUs at the cell site
- O-CU/O-DU split: centralized O-CU deployment where the O-DU is deployed at the cell site
- Fully centralized O-CU/O-DU: only the O-RUs are deployed at the cell site.

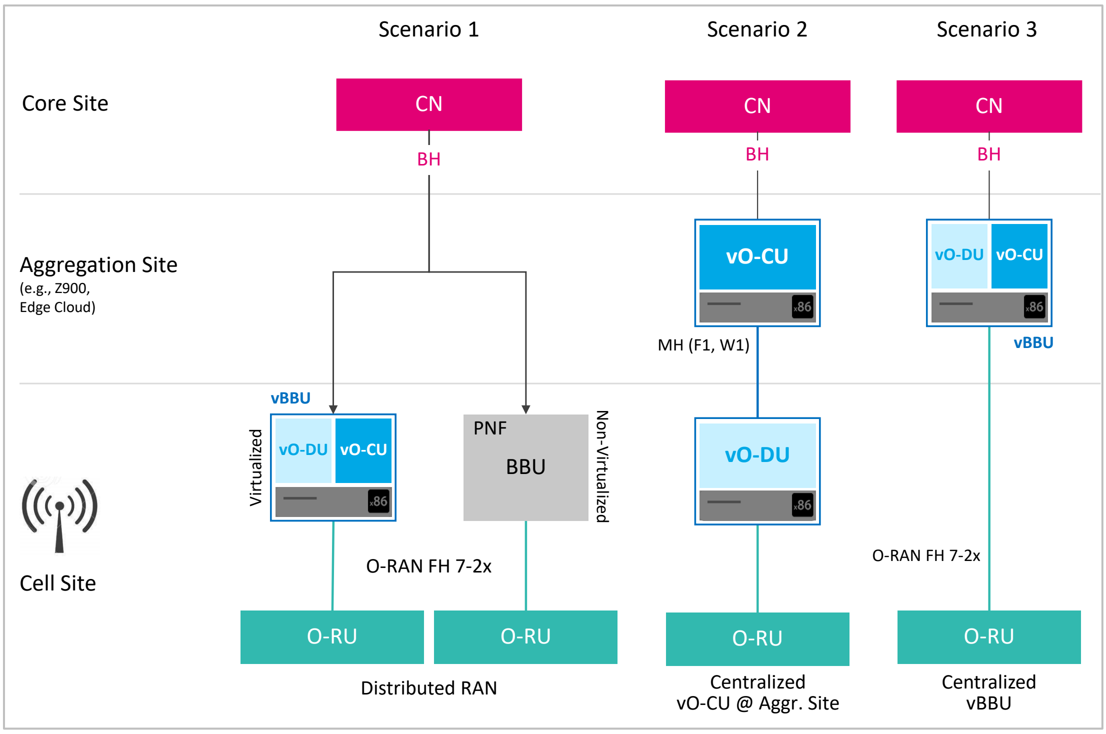

Figure 3: Different deployment options for open RAN: Scenario 1 - distributed open RAN deployment for virtualized or non-virtualized open RAN, Scenario 2 - centralized O-CU deployment of virtualized open RAN, Scenario 3 - centralized vO-CU and vO-DU deployment for virtualized open RAN

O-CU/O-DU Split is a further split of the baseband unit functions between the O-CU and O-DU functions, with central and distributed functions deployed at different locations and connected via the F1 (i.e. for NR) interface. O-CU/O-DU split is an attractive deployment option if there is no cost-effective transport network upgrade to allow for full O-CU/O-DU centralization (C-RAN). Locating RAN control functions in a central location provides potential performance improvement opportunities (e.g. interference coordination) as well as pooling gain.

3 COLLABORATION AS KEY TOWARDS MULTI-VENDOR SOLUTION DEVELOPMENT

In today's tightly integrated SRAN solutions, system integration is happening under one roof. The integration processes have been optimized over decades among the organizations and teams responsible for the various RAN sub-system components. However, the optimal processes and coordination required to manage the solution lifecycle in a multi-vendor environment is yet to be defined.

Successfully integrating and deploying a multi-vendor open RAN solution into an operator environment requires tight coordination among all parties during the whole lifecycle in their respective roles as operators, component or sub-system vendors and system integrators.

Expertise in different areas, from radio to cloud hardware and software, is a key success factor. All partners need to understand both their own domain and neighboring functionalities for a smoother interoperability.

Activities include alignment on open fronthaul IOT profiles and implementation options between O-RU vendor and O-CU/O-DU vendors, selection of server/Network Interface Controllers (NICs)/acceleration hardware and CaaS layer optimization for this choice as well as deployment and infrastructure observability considerations.

Different collaboration models can be defined as follows:

- Solution provider model: A system integrator takes overall responsibility for the end-to-end solution by interacting with the operator as a single entity in a manner similar to today's SRAN solutions)
- Partnership model: The operator ultimately takes end-to-end responsibility for the solution working closely with all sub-system vendors.

The chosen model depends on operator's preference and readiness to take more responsibility as well as dependencies on the ecosystem maturity, and organization and skills situation.

At this early stage of open RAN solution development, it is not yet clear what will emerge as the winning strategy. Therefore, it is important to trial and assess different approaches before the market coalesces around the most efficient collaboration model.

4 O-RAN TOWN OVERVIEW

RAN disaggregation and virtualization are huge transformational and disruptive forces for the whole ecosystem of vendors and operators. However, the biggest impact from this approach is seen in large scale, high-power and high-performance implementations of public mobile networks. Use cases like private networks or low power, low-capacity RAN solutions are less challenging and have a correspondingly lower impact on the industry and ecosystem. To achieve a better understanding of the technology, deployment, and operational challenges, we deployed an open RAN solution in our live environment in Germany, called “O-RAN Town”.

The key goal of O-RAN Town was to work with ecosystem partners to gain operational experience via a friendly user trial. This is an essential step before moving into scaled deployments.

We partnered with Fujitsu and NEC to provide the O-RU solution for both 4x4 MIMO antennas and massive MIMO Active Antenna Units (AAU) adopting O-RAN OFH interface (i.e. 7-2x split). Mavenir provided the O-CU/O-DU software and O-Cloud (excluding hardware) where they integrated all vertical components with the O-BBU hardware. Mavenir was also responsible for the horizontal integration for O-RU and O-DU/O-CU.

For the O-BBU hardware, Dell Technologies provided the server equipment based on Intel Ice Lake processors. The independent SMO is the other key component of Deutsche Telekom’s open RAN strategy. Deutsche Telekom’s inhouse developed solution based on ONAP was integrated and used in O-RAN Town. Mavenir also acted as system integrator, providing a horizontally and vertically integrated RAN solution suitable for integration by Deutsche Telekom into the SMO.

Deployment requirements and options

Disaggregated RAN integration and deployment into the operator environment is a major engineering task with many areas of consideration. One area relates to the architecture and design characteristics of the existing transport. Another area relates to the aggregation site characteristics. The need to process many frequency layers, including multiple MIMO layers, heavily influences the dimensioning of the deployed server hardware.

All these factors determine how an open RAN solution can be deployed, whether distributed, centralized or O-CU/O-DU split, as well as the type of servers to use – single socket or dual socket server hardware. Some important considerations are discussed below:

- Latency requirements in the transport network between the cell site and aggregation point to support centralized O-DU deployment: based on a 160µs latency budget between the O-RU and O-DU (which represents <32km of max. fiber length), not all the cell sites will fulfil this requirement even if directly connected by fiber. As redesigning the fiber infrastructure is hugely costly, O-DU aggregation will not be possible on many sites in Germany.

- OFH capacity requirements: Given a ten-fold increase in fronthaul transport capacity compared to backhaul, a new and more performant cell site gateway will be required with the support of 25 Gigabit Ethernet and 100 Gigabit Ethernet interfaces.
- Sites connected via Microwave (MW): MW technology is still used extensively to connect cell sites in our network. Transporting of the fronthaul over the existing MW links is not possible considering the capacity constraints of existing MW solutions. New "Fiber speed" wireless systems or new fiber deployment will be required.
- Sites connected in access ring topology: A limited amount of access rings will fulfil the fronthaul requirements due to strict latency of the fronthaul. A maximum number of sites per access ring is a limiting factor due to the fronthaul capacity. Breaking up the access rings into the point-to-point star topology is a solution.
- Depending on deployment scenarios (see Fig. 3), traffic encryption needs to be provided differently. Cell site is generally considered as untrusted location, so traffic encryption is required from end points located at the cell site. Different solutions should be realized depending on deployment scenario.

To gain experience with potential deployment scenarios, different options were considered for O-RAN Town (see figure 4). As the centralized RAN solution has not been extensively trialed in Europe, it was decided to make this deployment option the main focus. However, the following scenarios were deployed in O-RAN Town as not all sites could support centralization:

- Scenario 1 – Distributed RAN (vO-CU and vO-DU on cell site). User traffic carried over OFH is encrypted and O-CU/O-DU is deployed in untrusted location, therefore IPsec is needed on Midhaul (W1/F1) and on Backhaul (S1).
- Scenario 2 – Centralized vO-CU (vO-DU on cell site and vO-CU at aggregation location). User traffic carried over OFH is encrypted and O-DU is deployed in untrusted location, therefore IPsec is needed on Midhaul (W1/F1).
- Scenario 3 – Centralized RAN (vO-CU and vO-DU at aggregation location). User traffic carried over OFH is encrypted and O-DU/O-CU is deployed in trusted location, IPsec for traffic encryptions is not needed between Cell site and Aggregation site.

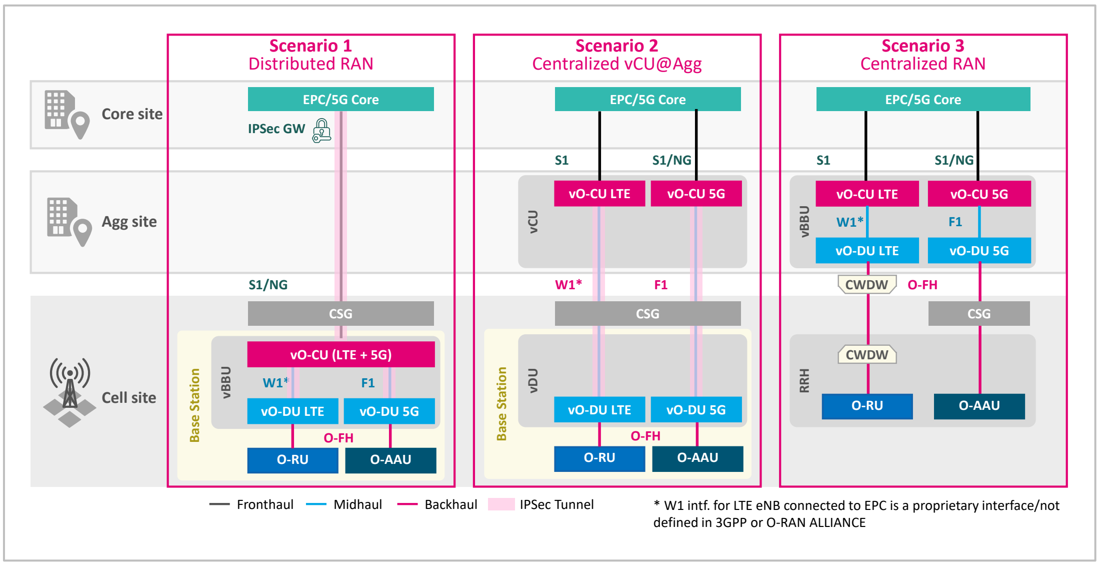

Figure 4: Different deployment options considered in O-RAN Town: (Scenario 1) distributed open RAN deployment with IPSec tunnel for W1/F1 and S1 interfaces, (Scenario 2) centralized O-CU deployment with IPsec tunnel for W1/F1 interfaces, (Scenario 3) centralized O-CU and O-DU deployment consideration

Furthermore, the O-RAN Town deployment was designed as an "overlay" network. The "overlay" concept enabled the network to provide the required level of control for dedicated tests and evaluations, as well as making it possible to provide demanding 5G service to friendly users. At the same time, regular connectivity services needed to be maintained to customers from the existing network infrastructure ("underlay") provided by the existing suppliers. As is typical for commercial network deployment, three -sector sites were considered. The next section describes related O-RAN Town network design and solution characteristics.

O-RAN Town system design

The open RAN architecture was deployed in the form of "overlay", whereby it is applied to selected frequency layers and Radio Access Technologies (RATs) on which the deployed open RAN equipment would operate. Additionally, the open RAN network is required to interwork with the existing network "underlay" provided by incumbent network vendors in order to ensure seamless service connectivity in the live network. An overview of the O-RAN network overlay is depicted in figure 5.

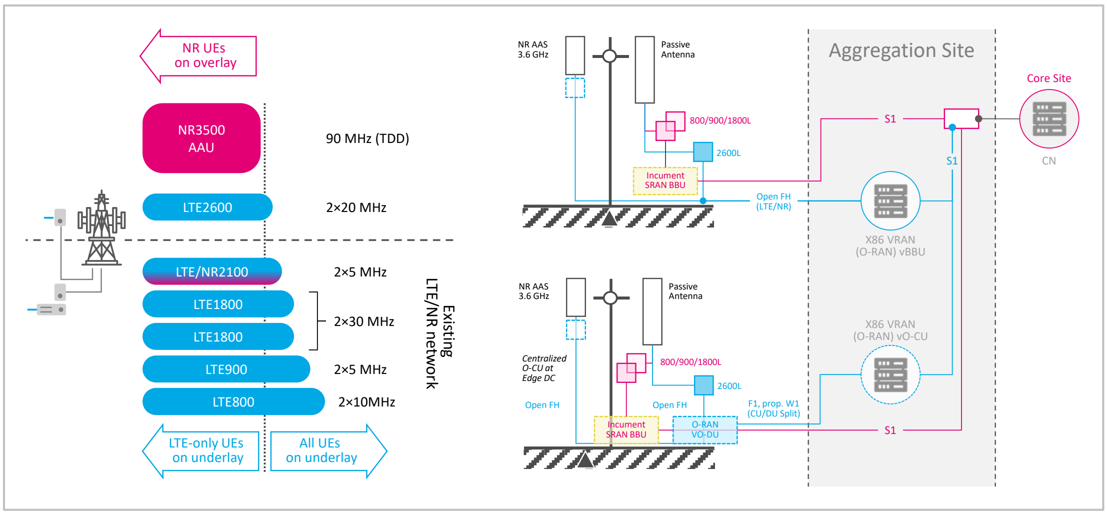

Figure 5: O-RAN Town overlay system design

In order to direct users to the open RAN overlay and ensure an enhanced overall performance level for all users, the following solution was implemented:

- Open RAN overlay operating on LTE 2600 MHz (anchor) and 5G NR (New Radio) 3600 MHz, in Non-Standalone (NSA) mode.
- Selective push of 5G capable devices to open RAN overlay: Dedicated frequency priority-based cell reselection occurs when signal levels are sufficient to enable use of wide bandwidth 3600 MHz spectrum. Access to open RAN overlay was limited to selected users defined for friendly customer trial using the mobility management entity (MME) whitelist.

Deployment was based on the 3GPP EN-DC architecture which is NR Non-Standalone employing LTE carrier as a control plane (CP) anchor for the 5G user plane (UP). Mobility was handled by/on the LTE layer with the NSA mobility options allowing secondary gNodeB addition and removal.

3GPP interworking principles were proven in terms of mobility operating between incumbent SRAN and open RAN networks.

The O-RAN Town design is based on Deutsche Telekom's live network solution. As Deutsche Telekom's RAN design is harmonized across incumbent SRAN vendors, the open- RAN solution design is aligned accordingly. For that reason, the engineering work included a detailed study of the Mavenir RAN software feature implementation and parameter ranges. In tight coordination with Mavenir, software updates were regularly released with new functionalities and features.

As the O-RAN Town solution coexisted with the incumbent underlaying SRAN, UE mobility design was developed to steer the terminals from frequency layers deployed by the incumbent SRAN vendor to the B7 frequency layer used by the Mavenir open RAN deployment (Fig. 6). Due to small scale and limited coverage of the O-RAN Town frequency layers, the mobility from the Mavenir B7 to incumbent SRAN frequency layers was also enabled.

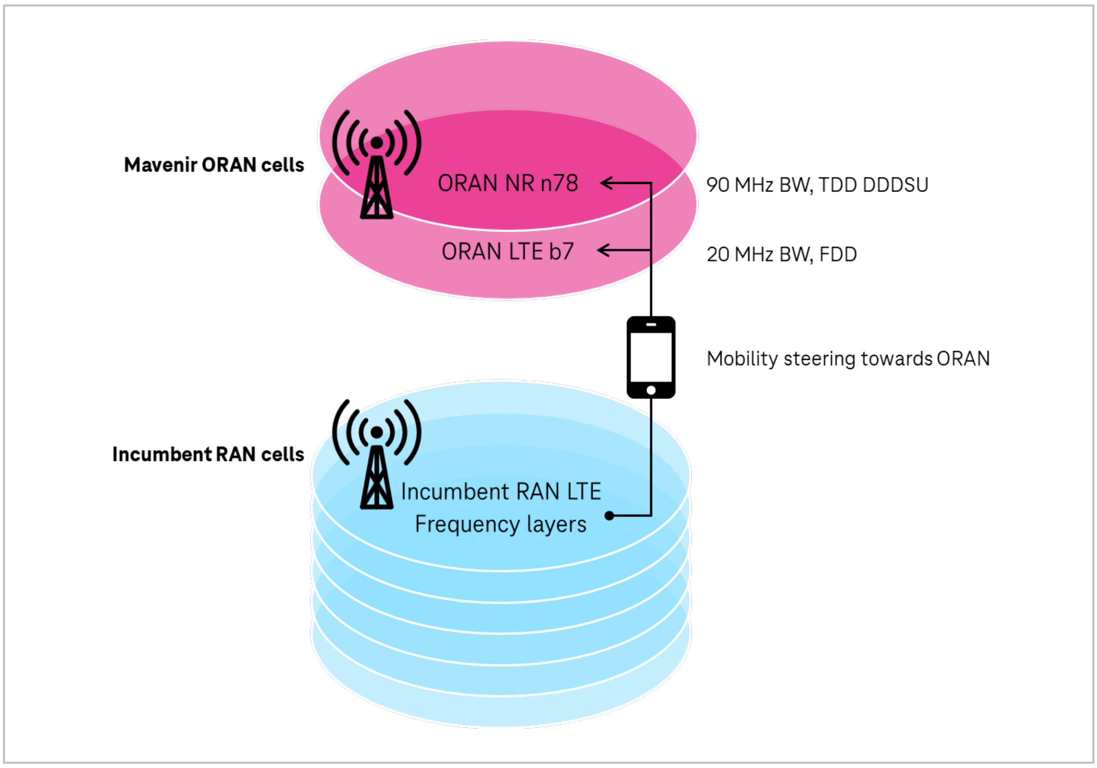

Figure 6: Mobility handling in O-RAN Town overaly concept

The main focus in O-RAN Town was on a centralized O-DU and O-CU deployment (pls. see Scenario 3 in Fig. 5). The key transport and related security design choices were as follows:

- Fronthaul: Packet based fronthaul with strict FH latency requirements.
- Midhaul: Local connection between vO-DU and vO-CU servers hosted at aggregation location. No IPsec required as aggregation location is considered secured.
- Backhaul: Packet passed L3 VPN Solution was used.

5 DETAILED VIEW ON MULTI-VENDOR SOLUTION

O-RAN Town deployment and operation was done in close collaboration with sub-system vendors as described in earlier section.

NEC

NEC provided Massive MIMO Radio Units (RU), 5G 32T32R AAS MB5420, aligned with O-RAN ALLIANCE specifications and ensured the seamless system integration and overall technical support for the project.

NEC developed a customized new 3.6 GHz variant to suit Germany's different frequency bands, as well as providing necessary software adaptations to allow deployment in O-RAN Town including frequency band adaptation, TDD Pattern, Physical random access channel (PRACH) format, etc. NEC closely coordinated with Mavenir to accelerate verifications and release software in a phased approach.

Overall, NEC's industry-leading Massive MIMO, including beamforming technology and system integration capabilities, enabled Deutsche Telekom to deliver the first successful European open RAN massive MIMO deployment & validation in O-RAN Town.

Figure 7: N78 5G 32T32R AAS (NEC)

Fujitsu

With the complete alignment to the aim of Deutsche Telekom and Fujitsu's strategy to widely spread and realize multi-vendor open RAN solution development, Fujitsu has participated in O-RAN Town and provided commercially ready O-RAN based Radio Units adopting to the German spectrum.

1. 4x4 N78 O-RU (Macro Radio Unit) for 5G
2. 4x4 B7 O-RU (Macro Radio Unit) for 4G

Tight coordination between Fujitsu and Deutsche Telekom teams for SMO integration and with the O-CU/O-DU vendor (Mavenir) for horizontal integration was needed for iterative software adaptations, deployment and operations including lab and field support by engineers.

With the activities above, Fujitsu contributed to the success of O-RAN Town proving that open RAN is an operable and innovative technology.

Figure 8: N78 5G Antenna External Macro Radio Unit & B7 LTE RRH in O-RAN Town (Fujitsu)

Dell Technologies

The hardware platform for the centralized management environment was based on Dell's 14th generation of PowerEdge Servers PowerEdge R640 & PowerEdge R740). These servers use Intel Cascade Lake CPUs with different core configurations. These were installed at the core site in Berlin, 140 km from the O-RAN Town radio sites in Neubrandenburg. Another critical component of these servers is the Intel network cards that provide speeds between 1 and 25 Gbit/s per Port.

For the deployment of the centralized O-Cloud, that is hosting the O-CU and O-DU functions, Dell's 15th generation of PowerEdge Servers (PowerEdge R750) has been used

(Figure 9). Powered by two Intel IceLake CPUs (Intel Xeon 6338N) with 32 Cores and two Intel ACC100 FEC accelerator cards these servers provide that best performance per watt that is currently available on the market. In addition, these servers used Intel networking cards (Intel E810 and X710) with different speeds per port.

For networking, Dell Technologies PowerSwitch S5232F-ON Switch has been used. Based on the Open Operating Systems OS 10, each switch provides up to 32 ports with 100 Gbit/s each. This allowed a flexible configuration for the different deployment scenarios.

All hardware components could easily be managed remotely based on the Dell Technologies iDRAC (integrated Remote Access Controller) interface. This functionality has been a crucial component to be able to manage the distributed setup of the environment.

As well as supplying the hardware, Dell Technologies actively supported the O-RAN Town ecosystem with expertise needed during the lifecycle management and during the operation of O-RAN Town.

Figure 9: Dell's 15th generation of PowerEdge Servers (PowerEdge R750)

Intel

Intel® Xeon® Processors

Intel has a strong roadmap, enabling vRAN to be delivered with uncompromised performance and meeting operators' key metrics. The 3rd Generation Intel® Xeon® Scalable processor used for O-RAN Town O-CU/O-DU workloads enables CSPs to benefit from the latest improvements in I/O, memory, storage, and network technologies. These improvements exhibit a performance improvement of 20-50% versus the previous generation Intel Xeon processor in RAN-related workloads, thanks to the specific instructions designed for that purpose.

Intel® vRAN Dedicated Accelerator ACC100

The DU server contained a standard PCIe add-in card with the Intel® vRAN Dedicated Accelerator ACC100 eASIC. One of the most compute-intensive 4G and 5G workloads is RAN layer 1 (L1) forward error correction (FEC), which resolves data transmission errors over noisy channels. FEC techniques detect and correct a limited number of errors in 4G or 5G data without the need for retransmission. FEC is a very standard processing function that is not differentiated across vendor implementations. Intel® vRAN Dedicated Accelerator ACC100 features a low-cost, power efficient acceleration solution for vRAN deployments based on Intel® eASIC technology. The ACC100 supports the open RAN, adopted BBDev API – an API which Intel contributed to the opensource community for FEC acceleration solutions. In addition, the 4th Gen Intel® Xeon® family will be built out with new chips with integrated acceleration that are optimized for vRAN workloads.

4th-gen Xeon Scalable platform will feature new, unique RAN-specific signal processing instruction enhancements in the CPU core, which will deliver significant capacity gains for vRAN and support advanced capabilities like high-cell density for 64T64R massive MIMO. This paves the way for customers to deploy vRAN in the world's most demanding environments.

Intel FlexRAN

Intel has invested heavily in a reference architecture called FlexRAN to accelerate RAN transformation. FlexRAN™ reference software contains optimized libraries for LTE and for 5G NR Layer 1 workload acceleration, including optimizations for massive MIMO. The FlexRAN reference software enables customers to take a cloud native approach in implementing their software utilizing containers. Mavenir O-CU/O-DU SW stack is based on Intel FlexRAN.

Mavenir

O-CU/O-DU

Mavenir open RAN solution is based on O-CU and O-DU disaggregation, which means all vBBU cloud-based components can be deployed independently at completely separate locations on different compute nodes.

Fronthaul between O-RUs (both 4G and 5G) and O-DU in Mavenir solution is Ethernet based and fully O-RAN 7.2x compliant. LTE radio units use 10Ge whist NR radio and active antenna units are connected with single 25Ge link, aggregated in the Cell Site Gateway (CSG) to a common 100Ge fiber link between the cell site and O-DU location.

When the O-CU is collocated with the O-DU at the same location, it was deployed in a separate compute node with both interconnected via a top-of-rack data center switch as part of O-RAN compliant mid-haul.

The whole deployment is maintained and orchestrated over the O-RAN O1/O2 based NB interfaces integrated through Mavenir element manager (mCMS) and performance data collector (mTA) into the SMO. Complete Operations, Administration and Maintenance (OAM) workloads including Smart Deployment as a Service (SdaaS) for terminating the M-Plane are deployed at the core data center in Berlin and are part of the one distributed Kubernetes cluster together with RAN components in Neubrandenburg.

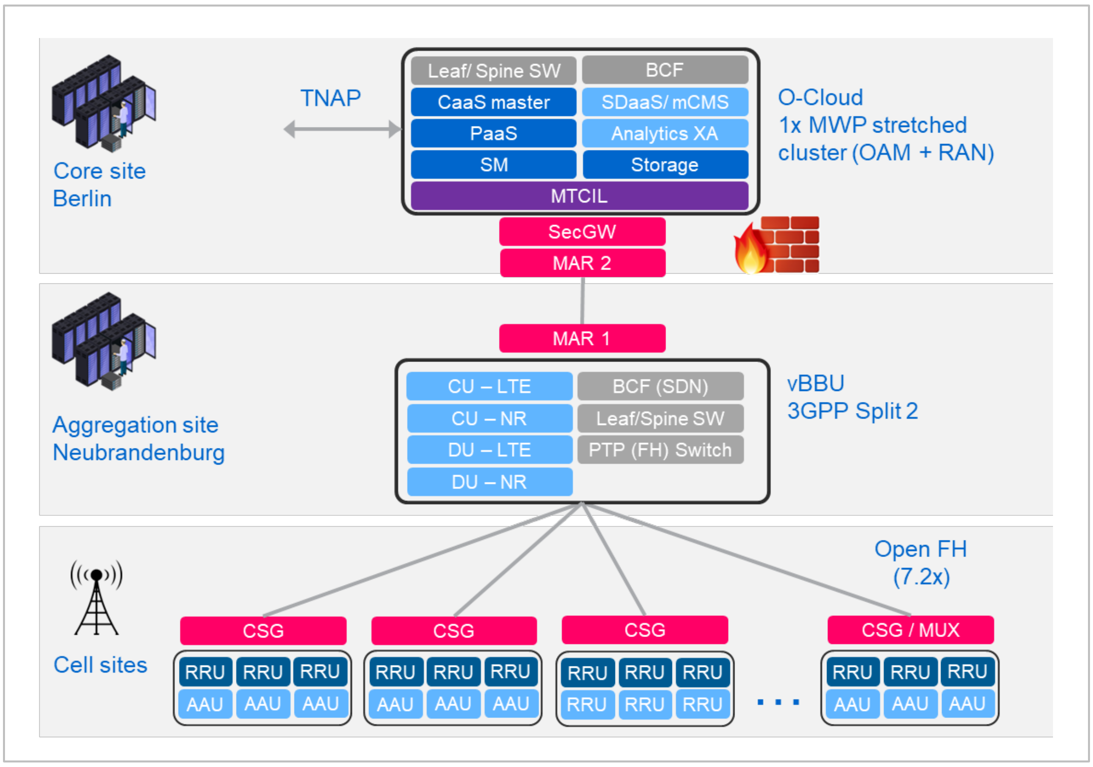

Figure 10: Detailed functional deployment for centralized O-CU/ O-DU deployment scenario

<u>O-Cloud</u>

The O-Cloud platform is composed of the physical infrastructure, supporting software components and management and orchestration functions to enable the deployment, operation and orchestration of the RAN software functions. The Mavenir open RAN solution is available on various O-Cloud platforms. The platform implemented in O-RAN Town is based on Mavenir's Webscale Platform (MWP), which is a next generation cloud-native solution that includes Kubernetes based CaaS, PaaS and MTCIL (Telecom PaaS layer) along with a management layer that includes full FCAPS, analytics and service orchestration. The platform enables cloudified solutions to be deployed using Dockerbased containers and relies on a Kubernetes environment for container orchestration and management.

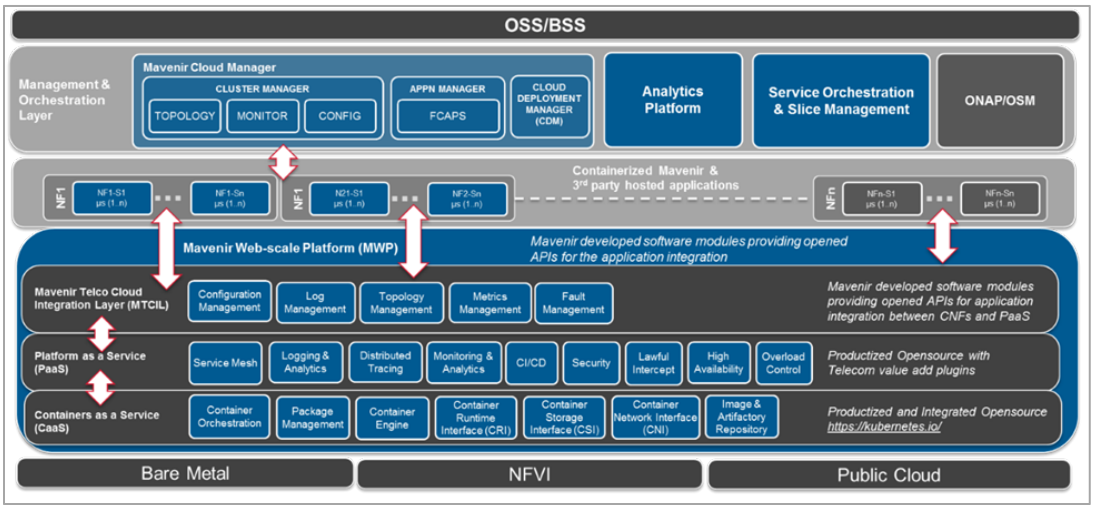

Figure 11: Mavenir Webscale Platform (MWP) O-Cloud platform

The layers shown in the diagram provide the following capabilities:

- Management & Orchestration layer - Includes the Cloud Manager (mCMS as Config manager, Fault manager and Topology manager), Analytics for monitoring, service orchestrators Northbound APIs to OSS/BSS
- Containerized application layer – Mavenir containerized CU and DU applications
- Mavenir Telco Cloud Integration Layer (MTCIL) - is a Telco PaaS layer that provides services, consisting of but not limited to, configuration management, fault management, log management, performance management, topology management, high availability, tracing, Call Detail Records (CDRs) and LI.
- PaaS - Productized open-source with Telecom value-add plugins
- CaaS –Components consisting of OS, container orchestration engine, container runtime interface, container networking interface, container storage interfaces, package management, image, artifact repository and monitoring components Kubernetes platform

In the target architecture, the Mavenir Digital Cloud Automation (mDCA) solution is introduced to automate the O-Cloud and O-CU/O-DU deployments with support of northbound O2 interface towards the SMO.

<u>System Integration</u>

Mavenir was responsible for the system integration in O-RAN Town. Mavenir integrated its own scope (O-CU/O-DU software, O-CU/O-DU hardware ordered by Deutsche Telekom, Mavenir Webscale Platform (MWP), cloud management with third party O-RUs from Fujitsu and NEC. The Mavenir open RAN stack was integrated into Deutsche Telekom's in-house developed SMO. Mavenir also executed the local installation and configuration on the radio sites. After commissioning, Mavenir carried out drive testing in the field, alarm monitoring and raised the necessary trouble tickets.

Mavenir offered a very close link between its project execution and its R&D organization. This provides great benefits especially during the early stages of open RAN evolution.

Release management and regression testing of the different components is a major challenge during the operational phase. The main effort assumed by the system integrator. CI/CD and test automation are essential to reduce the effort around open RAN solutions. The O-RAN Town pilot showed that a high degree of automation is fundamental to guarantee a successful open RAN deployment – especially when it comes to testing.

The system integrator needs an end-to-end understanding of O-RAN systems. A deep knowledge/understanding of the functionalities of the other vendors is required to create a stable system. O-RAN Town was an excellent opportunity for Mavenir to run the system integration in a multi-vendor environment. The learnings from this pilot and the broad expertise gained on all the open RAN components have prepared Mavenir for larger deployments.

Deutsche Telekom's SMO

The aim of Deutsche Telekom's engagement in SMO development was to trial the capabilities of a RAN vendor independent framework to manage the lifecycle of physical network functions (PNFs) and cloud-native network functions (CNFs). For the trial we integrated O-CU-CP (control plane), O-CU-UP (user plane) and O-DU network functions from Mavenir. On the architectural side, we used the O1 specs from the O-RAN ALLIANCE for the integration. By integrating the data and information model as YANG files and adopting the cloud native capabilities of e.g. HELM charts, we were able to create O-RAN services as a management baseline in the SMO framework. Through the vendor agnostic fault management (FM) and performance management (PM) data formats (VES and native Kafka) OSS modernization benefits were created and demonstrated.

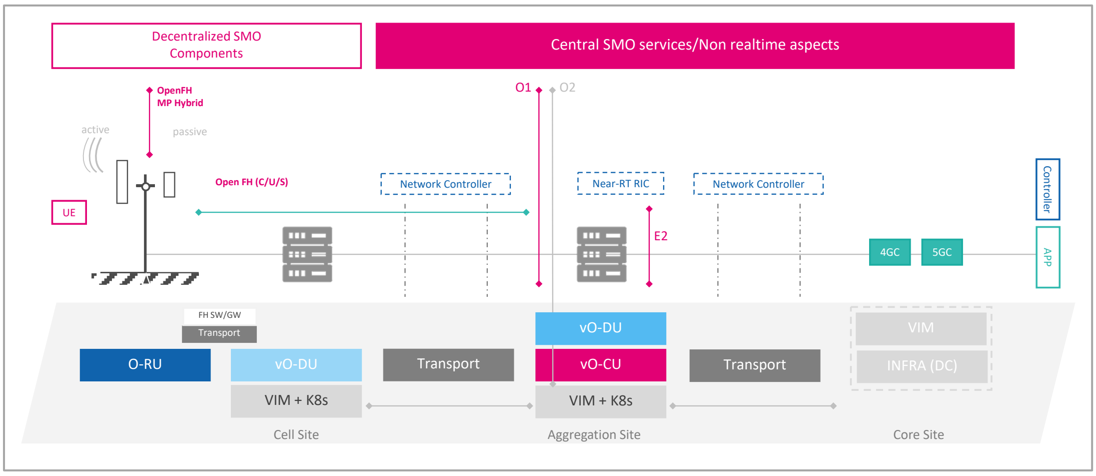

Figure 12: SMO Integration

O1 interface was mainly used to serve the operational aspects to manage the disaggregated mobile network. Those are known as FCAPS functions. Fault-, Config-, Accounting-, Performance- and Security-Management functions. The focus during the trial was on Fault-, Config- and Performance-Management. A cross functional hub for software development and specific RAN engineering was created to master the complexity of open RAN technology during Day 2 operations, focusing on service optimization (closed loop) and SON introduction.

6 MAJOR LEARNINGS AND ACHIEVEMENTS

The primary objective of O-RAN Town was to achieve the deployment of truly multi-vendor open RAN solution based on O-RAN ALLIANCE specifications and gain operational experience via a friendly user trial.

Deutsche Telekom, together with its technology partners, Mavenir, Dell Technologies, Intel, NEC and Fujitsu have successfully integrated an O-RAN solution into the live network of Telekom Germany. In the following sections, we describe some of the main highlights in terms of learnings and achievements.

RAN infrastructure solution

We have achieved integration of third-party NEC AAU and Fujitsu 4x4 MIMO with Mavenir O-CU/O-DU SW in O-RAN compliant open front-haul 7-2x 5G NSA solution. Massive MIMO functionality was verified and achieved the Europe first O-RAN based mMIMO call in Europe. Tight alignment between O-CU/O-DU vendor, O-RU vendor and Deutsche Telekom was required to assure interoperability and alignment on technical requirements. Applying an agile approach with fast delivery of necessary software adaptations is essential to assure proper system integration.

Similarly for O-CU/O-DU and O-Cloud, tight alignment is also needed. It has to cover hardware versions of all relevant components - Accelerator cards, NIC cards, switches, Small Form-factor Pluggable (SFPs), as well as all the firmware/software versions used in the open RAN solution. It is necessary to ensure a consistent approach to all components and a strong adherence to maintaining verified solution. Small inconsistencies could significantly impact on stability and performance.

SMO integration and network operation:

The main use cases in focus during the operational trial phase at O-RAN Town were:

- Automated cell site instantiation of O-RUs based on O-FH M-plane
- Service instantiation / CNF deployment
- Configuration management of deployed service instances (O-CU and O-DU)
- Service optimization (closed loop) and SON introduction

Leveraging the ONAP architectural blueprint and software baseline, Deutsche Telekom defined an SMO framework capable of RAN workload management based on several open-source components mainly under the Apache 2 license. The integration required for CNFs differ from classical VNF integration. SDOs like the 3GPP have defined standards to address this integration.

Configuration management was identified as the critical use case to enable further innovation in O-RAN. A differentiation was made between vendor specific and vendor agnostic artifacts, with the latter based on 3GPP standards. The integration of the Mavenir Yang models and corresponding config items allowed us to demonstrate vendor independence on the management layer. In the past, it has not been possible to manage the RAN network without vendor specific solutions (EMS – Element Management System).

Compliance to modeling aspects, data interfaces and protocols and a wide variety of config items is key to realize the SMO benefits.

With the combined experience of RAN solution integration and SMO integration, we are aiming to build the know-how and expertise on open RAN end-to-end solution integration to be able to control the solution. In the O-RAN Town trial we took on a very active role in the integration activity. Due to the early stage of the open RAN ecosystem the integration effort in O-RAN Town was quite high. A permanent alignment of the involved parties on a weekly basis was appropriate. In future deployments it will also be possible to rely on pre-integrated equipment combinations.

Installation and integration into the live network environment

A detailed preparation phase was required to ensure smooth installation of the open RAN solution by Mavenir. The main obstacles encountered during the preparation phase were related to regional differences between Asia and Europe, which caused delays and issues in the procurement and delivery processes for the required equipment (e.g. connector types). We also encountered delays in deliveries of latest equipment causing frequent changes in the planning and timelines.

Frequent software adaptations were required to deal with issues as they occurred, for example automatic and unwanted CPU clock reduction due to power supply/protection algorithm or issues related to sub-optimal hardware and software interactions). This was only possible with a tight alignment among all parties.

Deployment and operational experience

Major learnings were made from experiencing continuous development and validation of incremental improvements of solution maturity and performance. The O-RAN based solution that was deployed can operate as a standalone system or in coexistence and interworking with existing legacy deployments. Solution development, deployment and operation in an O-RAN ecosystem requires flexibility and agreed support processes between the involved parties. Traditional support processes that work well in IT environments are not sufficient in O-RAN deployment.

During the deployment and operational phase, the main issues encountered were related to software, stability and performance. Solving these issues required a lot of patches and software updates, and therefore a lot of testing in a lab environment.

There are number of areas to highlight as guidance for future initiatives:

- Tight interaction and transparent information exchange is essential throughout the entire project duration, encompassing the development, validation and integration, deployment and operations phases. A weekly alignment of the involved parties is appropriate.
- The complexity related to the high number of components from different vendors, stability and maturity makes detailed and high-quality documentation of the system essential. Issues should be properly tracked and managed including for the validation of frequent software updates and patches.
- Making software upgrades in a deployed open RAN solution can be cumbersome and costly. To drive efficient system integration and validation, it is essential to continuously optimize and automate software deployment and validation on compute nodes, as well as automating test execution.
- As open RAN is disruptive with interfaces and product implementations still in development, there are many issues still to overcome and processes to optimize, as well as limited availability or maturity of the tracing and observation functions required. To ensure minimized reaction and fault recovery times in a best-of-breed open RAN solution deployed and operated at scale, it will be essential that effective fault recovery and troubleshooting processes can leverage tools adapted for a multi-vendor environment.
- All integrated solutions need to be extensively tested in vendor/operator environment in terms of performance, functionality, and stability to ensure all required system parameters can be achieved. We have developed extensive test scenarios and procedures as well as test automation capabilities to ensure efficient validation of open RAN solutions. All our open RAN suppliers will be tested against that framework.

7 KEY FOCUS AREAS AS OUTLOOK

While it was not in the scope of Deutsche Telekom O-RAN Town, one challenging aspect of deploying open RAN commercially in many countries is the requirement to maintain 2G services into the future - even as most operators phase out 3G support.

Incumbent SRAN vendor deployments integrate 2G support so that common antennas, RUs and BBUs are shared by all technologies. As the scope of O-RAN specification only covers 4G and 5G, any open RAN solution must include a cost-effective support for 2G.

The large number of spectrum bands that need to be supported on 5G sites (e.g. 0.7, 0.8, 0.9, 1.8. 2.1, 2.6 and 3.5 GHz bands) demands a streamlined site implementation; this makes it problematic to also support a discrete overlaid 2G solution requiring separate RUs and antennas. To simplify site deployment and avoid the need to deploy extra antennas for 2G, Deutsche Telekom aims to use a Hybrid Radio Unit, supporting 2G in the 900 MHz band using a proprietary fronthaul interface, as well as 4G and 5G, using O-RAN OFH interface. The 2G BBU software and base station controller can either reuse existing non-virtualized products or, ideally through virtualization they can run on the same O-Cloud platform that supports the 4G and 5G baseband.

Energy efficiency and performance optimization are other urgent areas to address in order to accelerate open RAN solution adoption for large scale deployment. Open RAN deployments have to achieve performance and efficiency parity with, and eventually even outperform, integrated solutions.

Optimizing energy efficiency requires end-to-end analysis and benchmarking of the solution stack. New hardware generations will be expected to provide price and performance KPIs on a par with traditional RAN. In addition, new hardware generations will be designed to better serve the needs of a distributed deployment e.g. by supporting operations in environments up to 55 °C. We already see relevant hardware advancements in the roadmap of CPU vendors, that are expected to improve power consumption and overall efficiency of O-RAN implementations. One of these advancements involves accelerator functions located on the CPU die, which avoid the need to add accelerators as separate PCIe extension cards. Secondly, newly available inline accelerator products are promising an increased implementation efficiency based on their inline architecture as such, and the potential to offload a larger amount of software functions.

For example, Intel’s next-generation Xeon Scalable platform, based on the Sapphire Rapids CPU family, will be built out with new chips with integrated acceleration that is optimized for vRAN workloads. The integration of these functions will provide further power savings to customers as they build out their networks.

Due to rapid advances in standardized hardware components, such as CPUs, the lifecycle management for open RAN solutions also needs to be adapted accordingly.

For the O-RAN Town trial we took on a very active role in the integration activity. Due to the still early stage of the open RAN ecosystem in relation to the technology readiness and maturity, the integration effort in O-RAN Town was quite high.

We anticipate that for future deployments, it will also be possible to rely on pre-integrated equipment combinations. This is a development that will be facilitated by initiatives such as the i14y open lab and operated by a consortium of partners providing infrastructure and support for testing and integrating the components of open, disaggregated systems.

8 GLOSSARY

- 3GPP - 3rd Generation Partnership Project
- AAL - Accelerator Abstraction Layer
- AAU - Active Antenna Units
- ACC - Accelerator
- AI/ML - Artificial Intelligence / Machine Learning
- BSS - Business Support Systems
- CA - Carrier aggregation
- CAAS - Containers-as-a-Service
- CDR - Call Detail Records
- CI/CD - Continuous Integration and Continuous Delivery
- CNF - Containers or Cloud-Native Network Functions
- CPRI - Common Public Radio Interface
- CPU - Central Processing Unit
- COTS - Commercial Off-The-Shelf
- CP - Control Plane
- CSG - Cell Site Gateway
- CU - Central Unit
- C-RAN - Centralized RAN
- DSS - Dynamic Spectrum Sharing
- DU – Distributed Unit
- E2 – E2 interface
- eCPRI - enhanced Common Public Radio Interface
- EMS - Element Management System
- F1 – F1 interface
- FCAPS - Fault, Configuration, Accounting, Performance, and Security
- FM - Fault Management
- FW - Firmware
- gNodeB - next Generation Node B
- GPP - General Purpose Processor
- HW - Hardware
- IOT - Interoperability
- K8s - Kubernetes
- LCM - Lifecycle management
- LTE – 3GPP Long-Term Evolution technology
- MIMO – Massive Input, Massive Output
- MME - Mobiltiy Management Entity
- MTCIL - Mavenir Telco Cloud Integration Layer
- Near-RT RIC – Near-Real-Time RAN Intelligent Controller
- NF - Network Function
- NFVI - Network Functions Virtualization Layer
- NIC - Network Interface Controller
- Non-RT RIC - Non-Real-Time RAN Intelligent Controller
- NR - 3GPP New Radio technology
- NSA - 3GPP Non-Standalone
- O1 – O1 interface
- O2 – O2 interface
- OAM - Operations, Administration and Maintenance

- O-BBU – Open baseband unit
- OFH – Open Fronthaul
- O-Cloud – A cloud computing platform that meet O-RAN requirements to host the relevant O-RAN functions
- O-CU – O-RAN Central Unit
- O-CU-CP - O-RAN Central Unit control plane
- O-DU - Open Distributed Unit
- ONAP - Open Networking Automation Platform
- O-RAN – Open Radio Access Network
- O-RU – Open Radio Unit
- OS – Operating System
- OSS - Operation Support System
- PaaS – Platform as a Service
- PM – Performance Management
- PNF - Physical network function
- PRACH - Physical Random Access Channel
- R-APP - Real-time Application
- RAN – Radio Access Network
- RATS - Radio Access Technologies
- RIC – RAN intelligent controller
- RT - Real Time
- RU – Radio Unit
- SDaaS - Smart Deployment as a Service
- SFP - Small Form-factor Pluggable
- SMO – Service Management and Orchestration
- SON - Self Organizing Network
- SRAN – Single RAN
- TCO - Total Cost of Ownership
- TDD - Time Division Duplex
- UE - User Equipment
- UP - User Plane
- UPF – User Plane Function
- vRAN - virtualized Radio Access Networks
- X2 – X2 interface
- xAPP - A software tool used by a RAN Intelligent Controller (RIC) to manage network functions in near-real time