SAMSUNG

White Paper

vRAN Value Proposition and Cost Modeling

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EXECUTIVE SUMMARY

Virtualized RAN (vRAN) is a new architecture enhancing the flexibility of Centralized RAN (C-RAN) through the virtualization of the baseband function in a common resource pool made up of Commercial Off-the-Shelf (COTS) servers located in a centralized hub, allocating resources in a flexible manner according to traffic conditions.

vRAN provides outstanding value to operators thanks to the virtualization technology. This document highlights the general vRAN value proposition as follows:

- Flexible and adaptive capacity management via resource pooling and workload placement
- Lower total cost of ownership with unified hardware and software infrastructure
- Simplified network operation and maintenance through unified management
- Foundation for automated network slicing through dynamic resource scaling and function instantiation
- Enabling operation and service innovation using unified infrastructure and management

The whitepaper presents a TCO model to quantify the vRAN value proposition, leading to the following findings:

- C-RAN is the more cost-effective 5G RAN architecture over the long haul (with cumulated 5 years) than D-RAN by 14% less TCO.
- vRAN (based on C-RAN) is the more cost-effective 5G RAN architecture over the long haul (with cumulated 5 years) than D-RAN by 13% less TCO.

In conclusion, vRAN is clearly an attractive technology choice for operators in the long run from both qualitative and quantitative point of view.

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INTRODUCTION

0.1 TERMINOLOGY

Throughout this document, vRAN refers to the architecture in which virtualized basebands (vDU) are placed in a centralized HUB and C-RAN refers to the architecture in which DUs (DU) are placed in a centralized HUB. Meanwhile, D-RAN refers to the architecture in which DU is placed at cell site.

0.2 PURPOSE

The purpose of this document is two folds:

- First, to present general vRAN value proposition;
- Second, to determine a more economical 5G RAN architecture from the Total Cost of Ownership (TCO) point of view.

0.3 SCOPE

This document first presents general vRAN value proposition in several areas. And TCO models are presented to quantify vRAN advantages.

0.4 Revision History

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0.5 ABBREVIATIONS

CAS Converged Access Switch
COTS Commercial-Off-the-Shelf
CAPEX Capital Expenditures
CSR Cell Site Router
DU Distributed Unit
vDU Virtualized Distributed Unit
DSS Dynamic Spectrum Sharing
FHG Fronthaul Gateway
OPEX Operating Expense
vRAN Virtualized Radio Access Network

vRAN Value proposition

vRAN is a new architecture enhancing the flexibility of Centralized RAN (C-RAN) by virtualizing the functions of basebands in a common resource pool made up of the Commercial Off-the-Shelf (COTS) servers located in centralized Hub, allocating resources in a flexible manner according to traffic conditions.

This section highlights a number of outstanding value propositions associated with vRAN.

1.1 FLEXIBLE AND ADAPTIVE CAPACITY MANAGEMENT

The network function virtualization and cloudification of vRAN, and its deployment at various scale spanning site, far edge, edge, and core clouds facilitate the flexible and adaptive capacity management. For instance, when more traffic is observed from some cell sites, or the number of UEs is observed to increase, vRAN allows the operator to dynamically change the cell capacities for those cell sites. Likewise, when less traffic comes from other cell sites, or the number of UEs is observed to decrease, the corresponding cell capacities can be dynamically changed.

Resource pooling also represents the benefit of vRAN's flexible and adaptive capacity management. The higher level of resource pooling gain is achieved as the more centralization is applied on account of a centralized Cloud RAN architecture which is conducive to the improved utilization of DU processing resources at a larger pool. Further improvement of resources comes with cloud-native containerization technology where resources are more dynamically and optimally allocated on a micro-service level.

Another benefit of vRAN's flexible and adaptive capacity management is the energy savings operation for under- or less-utilized vDU servers. This comes with the ability to move workload flexibly depending on traffic conditions. For instance, when DUs are distributed or centralized, under-utilized workload at certain time (e.g., at night) can be re-assigned and aggregated into another vDU server to reduce the total number of active servers. Alternatively, the operator can dynamically enable the CPU power savings mode in a vDU server with under-utilized workload.

In summary, vRAN's flexible and adaptive capacity management offers several benefits that would lead to avoid over-provisioning of RAN capacity dimensioned for peak traffic demand. This also facilitates a practical and affordable capacity scalability that avoids unnecessary vDU server investment.

1.2 LOWER TCO BY UNIFIED HARDWARE AND SOFTWARE INFRASTRUCTURE

The use of generic, unified COTS hardware unit reduces operational and training costs incurred by running and managing vendor-specific HW units. It also relieves the operator of both vendor lock-in and associated HW-bundled proprietary configuration issues, which typically results in high operational costs and the limitation of HW portability across different vendor domains inside the network.

This generic unified COTS hardware unit also simplifies hardware management and removes costly management of vendor-specific hardware. In addition, when upgrading to higher capacity servers, the existing servers can be re-deployed for use in running other applications such as Core, MEC applications, and IT applications. This repurposing of the existing COTS HW unit to another business operation in its network is a clear advantage of vRAN. In contrast, the reusability of purpose-built proprietary hardware is limited or at best is only possible within specific vendor and/or is bound to the particular 3GPP wireless standards release.

Multi-vendor management becomes much easier with vRAN as the operator is able to run simultaneously vendor-specific RAN software as a separately containerized application on same COTS hardware units. For example, a typical RAN sharing between two operators in the rural sites can be made possible by running separate gNB on the same shared COTS hardware units.

Other operational advantage of vRAN comes with the case where auxiliary dedicated sled-type servers or hardware accelerators can be easily plugged in. Thus, no need for purchasing or replacing the existing vDU server arises. All of these aforementioned benefits are not exhausted list, and they corroborate the advantages of vRAN in lowering the total cost of ownership.

1.3 SIMPLIFIED NETWORK OPERATION AND MAINTENANCE

The use of both generic unified COTS hardware and the containerized software technology provides the homogeneous hardware and software infrastructure for RAN as well as other NFs (e.g., Core, IMS, etc.). On account of this homogenous infrastructure, the operators can simplify their operation and maintenance practices to ease the tasks in capacity scaling or dimensioning, fault and performance monitoring, and upgrading software. Through a simplified operation process, operational efficiency is greatly improved

As vRAN software is utilizing Open Sources (e.g., OpenStack, K8s, ONAP, etc.) and 3rd party cloud management solutions (e.g., Redhat, VMware, public cloud infra management solutions from AWS, MS Azure, Google GCP), the seamless software upgrade available in the web-scale applications can be also applied in the Telco software management. For example, rolling updates in K8s makes this possible. Thus a vRAN node running 2G/3G/4G/5G technologies can simultaneously upgrade a specific technology without disrupting services in other technologies.

This simplified, seamless, and unified management in conjunction with Open Source cloud infrastructure management solutions minimizes the management complexity when running multiple sets of software in the same node or network. It also improves operational efficiency to a different level by streamlining and automating the network operation and maintenance process.

1.4 FOUNDATION FOR AUTOMATED NETWORK SLICING

Network slicing allows operators to create and run multiple virtual networks that are designed to meet the needs of specific user groups (services) over the shared physical infrastructure. These virtual networks have different needs for bandwidth, latency, reliability, security, coverage and service levels; and therefore, they need to be optimally designed to serve specific needs over the shared resources.

As the network slicing services are expected to be in widespread use in different business needs, it is essential to reduce the management complexities of the network slicing operations by automation; e.g., automating the network slicing lifecycle management and SLA assurance on new slice service requirements. Without proper automation in place, it is almost impossible to deliver the promise of network slicing: the delivery of new diverse services from various industry verticals on the fly in a cost effective manner.

Key software foundation for the automated network slicing operation benefitting from vRAN's virtualization and cloudification capabilities are as follows:

- Automated instantiation of the RAN slicing service when and where it is required. Slice-specific network functions and micro-services are more flexibly deployed in vRAN than in a conventional RAN with manually–deployed purpose-built proprietary DU.
- Automated capacity scaling in RAN slicing when and where it is required for a timely response to unexpected traffic demands, without overprovisioning resources. In such environment, vRAN is conducive to adaptive and optimal resource allocation required per slice in radio and computing resources as well as fronthaul and backhaul transport resources.
- Automated scheduling differentiation in RAN slicing by means of RAN-slice aware policy enforcement that influences gNB radio resource management and scheduling optimization.
- Automated integration of additional services as needed. For example, any Cloud-native Open Software such as data management platform and analytics tools can be easily instantiated atop vRAN deployment.

In summary, the automation is an essential element for delivering the promise of the network slicing: the agile delivery of network slicing services in various business environments. vRAN's virtualization and cloudification serve as a key foundation for the automated network slicing.

1.5 ENABLING OPERATION AND SERVICE INNOVATION

The virtualization and cludification technology is viewed to the operators as a means to better enable service and application agility. Moreover, it is also viewed as a unified infrastructure to create operation and service innovations where RAN, CN, Edge applications run mixed on the same node, or can run over several cloud nodes depending on the service requirement and application characteristics.

Here are some examples of operation and service innovation where this flexible workload (e.g., applications or functions) placement and configuration can be realized for the operators:

- The operator can place vRAN on the same cloud to reap the benefits of running RAN functions and open applications easily and efficiently. For example, MEC with some analytics capability can be deployed on the same private cloud servers or in the public cloud servers (e.g., Amazon, Microsoft, Google).
- The operator can build a compact, small form factor configuration that hosts vRAN (Baseband, CU-UP, CU-CP), as well as CN UPF and MEC applications together on the same COTS servers. This compact configuration can be a best fit to the business use case and deployment scenario where hosted services (e.g., self-driving, tele-surgery, robotic remote motion control) are latency sensitive (<1ms) and facility space is limited. Such compact configuration is also beneficial to the operator looking to the foot-print efficient inbuilding solution.

In summary, vRAN gives the operator a competitive edge enabling operation and service innovation.

TCO MODEL

2.1 SCOPE OF TCO MODELING

Typically, TCO comprises both the CAPEX and the OPEX for Radio, Baseband, and Transport Unit (TU) (switching equipment and dark fibers). The CAPEX is one-time equipment purchase cost and the OPEX is annually recurring costs used to maintain the network equipment.

The CAPEX and OPEX of Radio in this analysis is not included because it is assumed to be same for both RAN architectures, D-RAN with DU and C-RAN with vRAN.

The following table shows the cost component matrix used in the present TCO analysis. TCO is then compared with the two RAN evolution options: D-RAN with DU and C-RAN with vRAN.

※ TCO analysis of the D-RAN with vDU architecture is excluded because the TCO of D-RAN with non-virtualized DU depends on only DU CAPEX and other costs such as transport CAPEX and OPEX are similar to the D-RAN with vDU architecture.

Table 2-1 : Cost Component Matrix in the TCO Analysis

Cost Component		CAPEX	OPEX
Radio	Radio equipment (Radio, Massive MIMO radio)	**Not included**	
	Energy consumption costs by Radio equipment		**Not included**
Baseband	Baseband equipment (DU, vDU)	○	
Transport	Energy consumption costs by Baseband equipment		○
	Switching equipment & modules	○	
	· D-RAN : CSR (Cell site), CAS (Central DC)		
	· C-RAN : FHG (Cell site), CAS (Hub site/Edge DC)		
	Dark fiber	○	
	Energy consumption costs by switching equipment		○
Site Rental	Rental cost of cell sites, C-RAN hub sites		○
OAM	Maintenance fee, estimated as a fraction of DU CAPEX		○

2.2 ASSUMPTION

2.2.1. NETWORK AND CELL-SITE CONFIGURATION

It is assumed that the baseline D-RAN consists of 5C (carrier) 3S (sector) configurations per cell site (i.e., 15 cells per site) and a single C-RAN or vRAN hub site is capable of hosting 20 cell sites(15cells per cell site).

The reference 5G site cell configuration is defined as follows

- NR 700/850 10MHz 4T4R 2C 3S with DL/UL 4L/2L layer each, 30k SCS
- NR AWS/PCS 20MHz 4T4R 2C 3S with DL/UL 4L/2L layer each, 30k SCS
- NR C-Band 100MHz 64T64R 1C 3S with DL/UL 16L/8L layer each, 30k SCS

Note that Dual-band Radios are assumed to be in use for the 700/850 and AWS/PCS carriers, respectively, and Massive MIMO radios are assumed for C-Band 100MHz cells.

2.2.2. BASEBAND

Baseband dimensioning is based on the specifications of the traditional baseband(DU) and the current and upcoming vRAN solution (vDU)

- vRAN Phase1 is based on current Intel CPU and hardware accelerator.
- vRAN Phase2 is based on new CPU and hardware accelerator, and the performance is estimated to be improved by 2 times.

The price structure of the DU and vRAN used in this cost modeling are assumed as follows:

Table 2-2 : Price structure and assumption of DU and vDU

	DU	vDU
Price Structure	1 x main board + n x channel cards	COTS HW Cost + SW License + Cloud Platform

2.2.3. FRONTHAUL

The fronthaul options are assumed as follows:

- In D-RAN, the legacy CPRI fronthaul option is assumed.
- In C-RAN, the standard eCPRI function split Option 7-2x [3] is assumed.

2.2.4. TRANSPORT

- Self-built transport solution over dark fiber is assumed.
- Transport CAPEX consists of transport equipment (e.g., CSR, FHG, CAS) cost and dark fiber rental cost.
- Transport dimensioning is based on real equipment (real CSR, FHG, CAS).
- Transport network (i.e., fronthaul/midhaul) is dimensioned with a rule of 80% utilization with 1+1 redundancy.
- Annual dark fiber cost: Usually long-term (e.g., 30 years) rental is paid with the cost of $50/mile/month. In this study, 20 miles of fronthaul is assumed; and the dark fiber costs are considered as CAPEX, annually amortized over 30 years.

2.2.5. OPEX

The following OPEX parameters are assumed as follows

Table 2-3 : Assumptions on the OPEX Related Parameters

Site Cost	· Cell site rental cost Includes cell tower, cell site floor space for basedband & maintenance. - D-RAN : $33,000/month - C-RAN : 80% of D-RAN · Edge DC cost (C-RAN) - OPEX per rack : $3,300/month
Energy Cost	· Includes the power consumption of baseband and air conditioning & rectifier for baseband. · $0.14/kWh
OAM Cost	· Includes HW & SW maintenance fee, site visit for baseband capacity upgrade, network fault management, performance optimization, etc. · D-RAN/DU: 20% of DU CAPEX C-RAN/vRAN : 50% of D-RAN/DU (50%↓by C-RAN, +20%↓by vRAN automation)

2.3 REFERENCE NETWORK SIZE AND MODEL FOR TCO ANALYSIS

2.3.1. D-RAN REFERENCE MODEL

Figure 1-1 shows the network diagram of the D-RAN reference model with 20 sites of 300 cells, where traditional D-RAN baseband is located in the cell site and virtualized CU is located at the hub site. The aggregated midhaul traffic bandwidth for D-RAN, following the 1 peak and 2 averages per carrier, is also shown in Table 2-4. Given the estimated midhaul aggregated bandwidth, it is sufficient to put the 25GE link (two 25GEs 1+1 for link redundancy) in the midhaul transport network. Additional transport equipment such as CSR at cell site and CAS at the hub site is appropriately dimensioned to support this model.

Figure 2-1 : D-RAN Reference Model

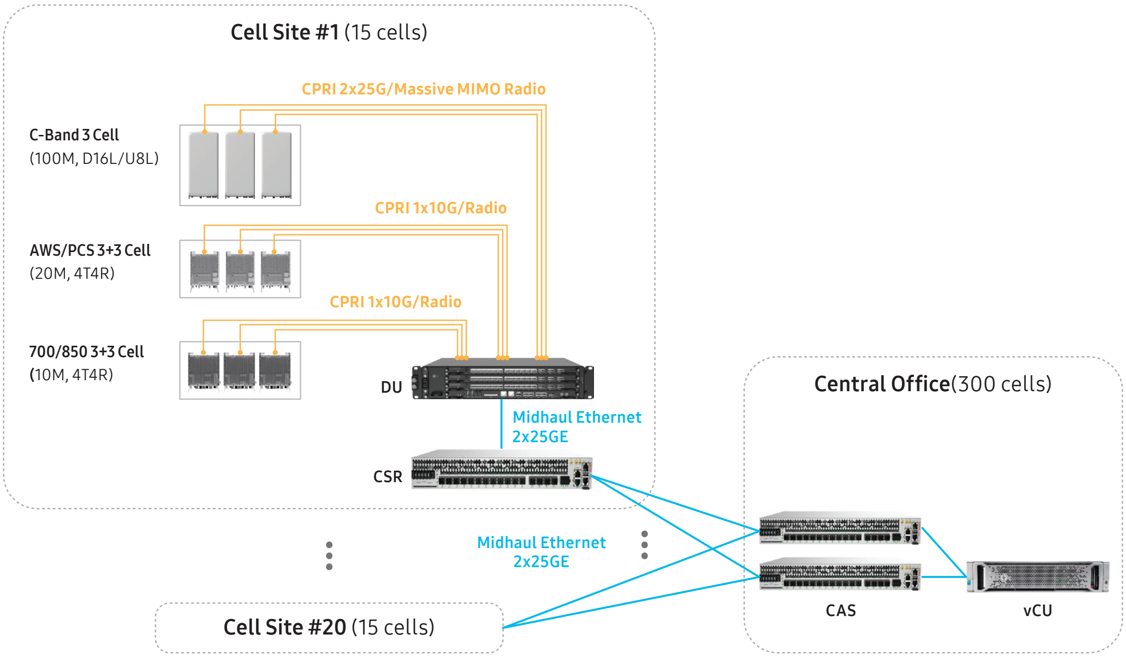


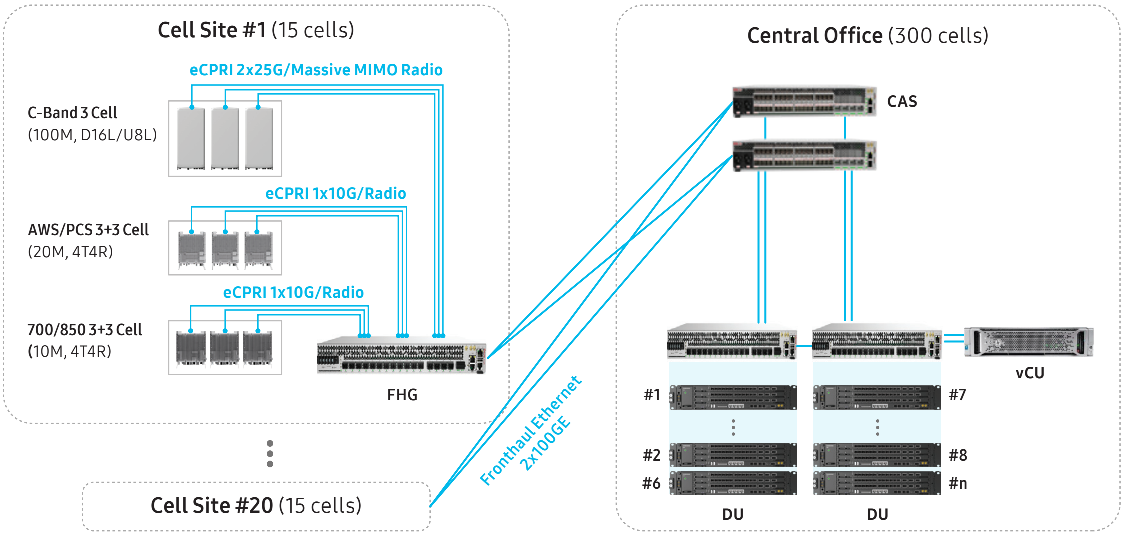
Table 2-4 : Estimated Midhaul Aggregated Bandwidth for D-RAN

	Midhaul BW (1 Peak + 2 Avg.)	Cell Peak Tput (256QAM)	Cell Average Tput (ITU-T : Peak x 0.2)
C-Band 64T64R Massive MIMO radio 3Cell (100M D16L/U8L)	10 Gbps	7.2Gbps	1.4 Gbps
AWS/PCS Dual-band 4T4R radio 6Cell (100M D16L/U8L)	1 Gbps	359 Mbps	72 Mbps
700/850 Dual-band 4T4R radio 6Cell (10M D4L/U2L)	0.5 Gbps	180 Mbps	36 Mbps

2.3.2. C-RAN REFERENCE MODEL

Figure 1 2 shows the network diagram of the C-RAN reference model with 300 cells per 1 C-RAN hub site, where Radio/Massive MIMO radio is located in the cell site, but DU is collocated with vCU at the hub site. As shown in the figure, the total number of DUs is reduced to 11 DUs compared to the D-RAN 30 DUs because of the DU pooling effect (in other words, DU hoteling effect) thanks to the full channel card configuration per each DU at the hub site that can afford more sites given the reference cell site configuration.

Figure 2-2: C-RAN Reference Model



The interface between the cell site and the hub site follows the standard eCPRI interface over the Ethernet fronthaul. The supported function split option is eCPRI standard Option 7-2x and the estimated aggregated fronthaul bandwidth is around 100Gbps. Thus, it requires two 100GE links to be in place (1+1 link redundancy). In addition, the C-RAN hub site needs to install a new fronthaul gateway capable of more aggregated eCPRI traffic with 100GE links. The estimated eCRPI fronthaul aggregated bandwidth for C-RAN is shown in Table 2-5.

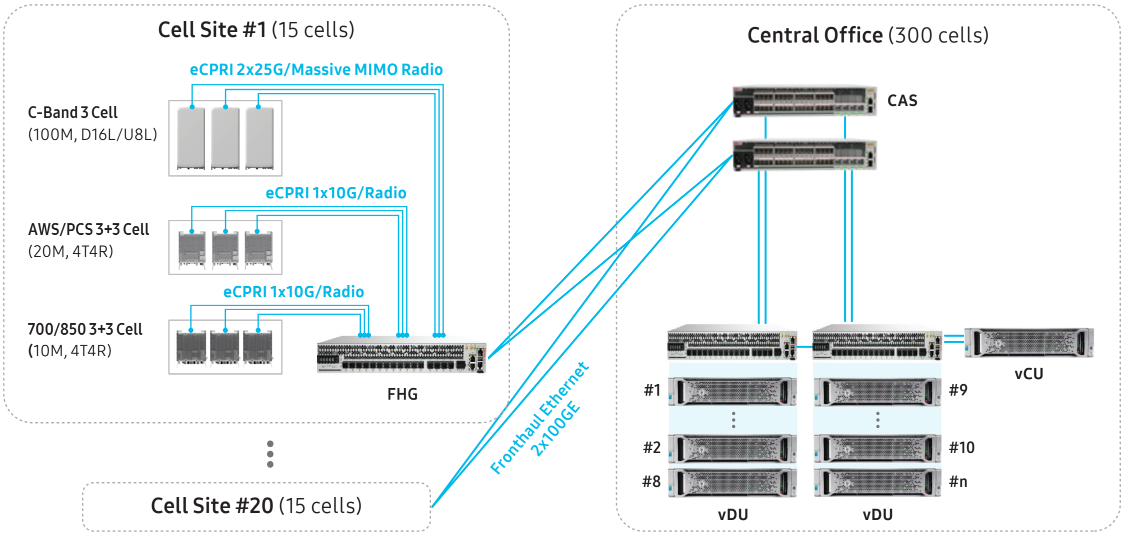
Table 2-5 : Estimated eCPRI Fronthaul (Option 7-2x) Aggregated Bandwidth for C-RAN

	Fronthaul BW (1 peak+2 Avg.)	FH Peak Tput./cell (IQ bitwidth: 14)	FH Average Tput./cell (Peak x 0.2)
C-Band 64T64R Massive MIMO radio 3Cell (100M D16L/U8L)	61.6 Gbps	44Gbps	8.8 Gbps
AWS/PCS Dual-band 4T4R radio 6Cell (20M D4L/U2L)	6.2 Gbps	2.2Gbps	0.44Gbps
700/850 Dual-band 4T4R radio 6Cell (10M D4L/U2L)	3.1 Gbps	1.1Gbps	0.22Gbps

2.3.3. VRAN REFERENCE MODEL

Figure 2-3 shows the network diagram of the vRAN reference model with 300 cells of 1 vRAN hub site, where Radio/Massive MIMO Radio is located in the cell site, but DU is replaced with vDU and is also collocated with virtualized CU at the vRAN hub site.

Figure 2-3 : vRAN Reference Model



There is no change in the fronthaul configuration from C-RAN case. The interface between cell site and hub site follows the standard eCPRI interface over the Ethernet fronthaul. The supported function split option is eCPRI standard Option 7-2x and the estimated aggregated fronthaul bandwidth is around 100Gbps, which requires two 100GE links to be in place (1+1 link redundancy). In addition, the vRAN hub site needs to install a new fronthaul gateway capable of more aggregated eCPRI traffic with 100GE links.

TCO COMPARISON RESULTS

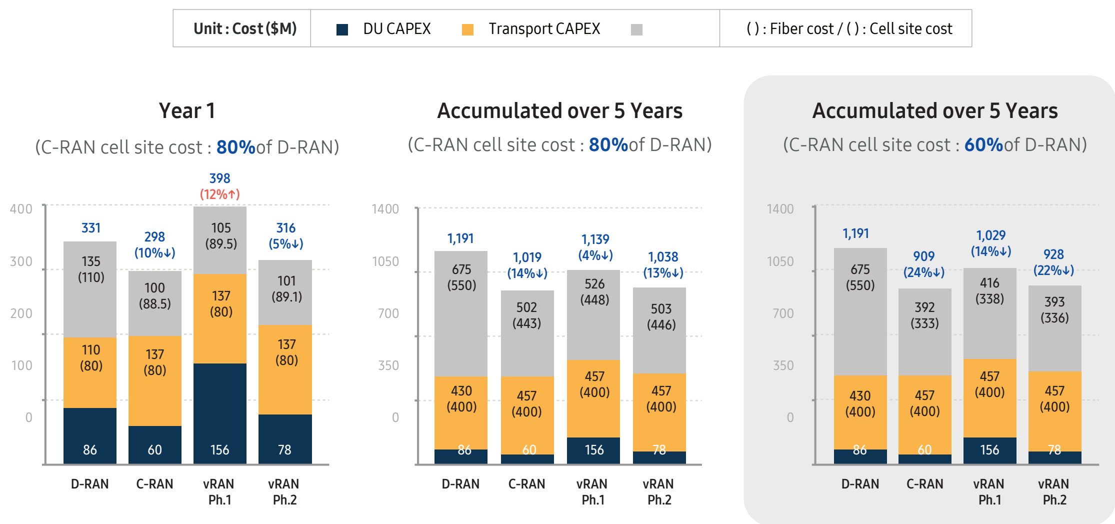
Given the three reference models above, we've obtained the following 5-year accumulated TCO comparison results:

- TCO savings: C-RAN reduces TCO by 14%; vRAN Ph.1 reduces TCO by 4% and vRAN ph.2 reduces TCO by 13% as compared to D-RAN TCO respectively.

(Note: Recall that the above percentages are based on the assumption that C-RAN cell site rental cost is 80% of that of D-RAN. If C-RAN cell site rental cost is assumed as 60% of that of D-RAN, C-RAN reduces TCO savings by 24%; vRAN Ph.1 reduces TCO by 14% and vRAN Ph.2 reduces TCO by 22% as compared to D-RAN TCO respectively.)

- C-RAN/vRAN CAPEX savings shows about 30% gains as compared to D-RAN, due to the DU Pooling (Hoteling) effect.
- C-RAN/vRAN OPEX savings shows about 25% gains as compared to D-RAN due to the centralization effect.
- C-RAN/vRAN Transport CAPEX increased by about 6% (25% for Year1) due to the increase fronthaul bandwidth in C-RAN/vRAN Option 7-2x as compared to the D-RAN midhaul Option 2 [4,5].

Figure 3-1 : TCO Comparison of D-RAN, C-RAN, and vRAN over 5-year periods



Based on the TCO comparison results, the important areas of TCO optimization for 5G RAN are highlighted as follows:

- OPEX optimization: More than 50% of TCO is caused by OPEX regardless of D-RAN, C-RAN, and vRAN. Target OPEX optimization costs are the site rental cost, energy consumption cost, site visits cost, operational personnel cost with automation efficiency in the workflow and troubleshooting. Note that in the present TCO study, not all areas are explored. This should be further tuned, incorporating per-operator specific calculation with more information.

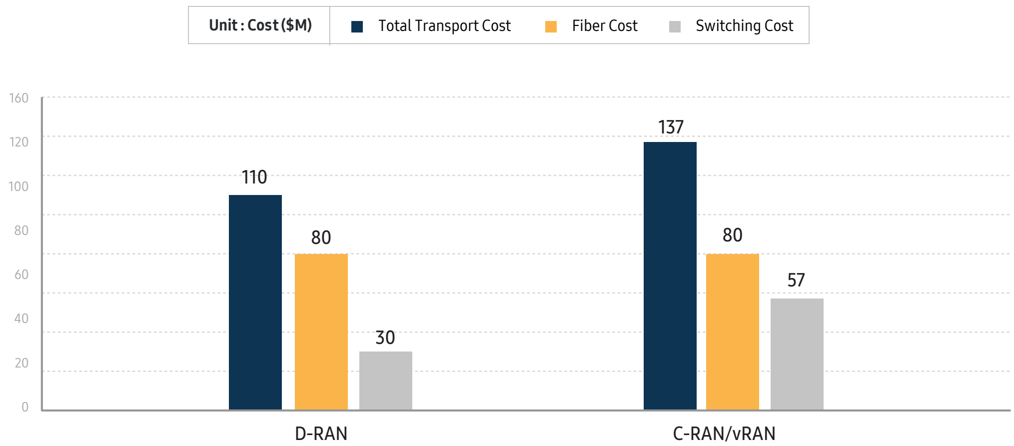
- Transport CAPEX optimization: About 40% of TCO incurred by Transport. Thus, this leads to bandwidth-efficient fronthaul solutions. Supporting only one single function split option may not be optimal given that there are various 5G deployment scenarios with a mix of low-band 600/700MHz, mid-band 2.5G/3.7G/3.9G, and high-band 24G/28G/39G carriers. Thus, the capability to support different fronthaul split options simultaneously is desired even in the single cell site.
- Baseband CAPEX optimization: Technological advances in the COTS H/W platform and accelerators tend to improve DU CAPEX, but more SW oriented optimization is desired. Efficient vDU and resource pooling via SW function virtualization should be devised to achieve more affordable UEs, cells, or site capacity per vDU.

3.1 TRANSPORT CAPEX DECOMPOSITION

The Transport costs are further broken into switching equipment cost and dark fiber installation cost. Typically, mobile Ethernet backhaul is leased from the Carrier Ethernet providers, or built over the long-term (e.g., 30-year) leased dark fibers. Or some operators had been building their own dark fibers as part of their converged wireless and wired access for their own access use or access service for other operators mobile backhaul uses.

The study results in the Figure 1-5 reveal that D-RAN switching equipment cost is about 52% level of C-RAN/vRAN, and fiber cost is the major cost factor for the transport: 73% (D-RAN), 58% (C-RAN/vRAN).

Figure 3-2 : Transport Cost Decomposition: Ethernet switching equipment cost vs. Fiber cost

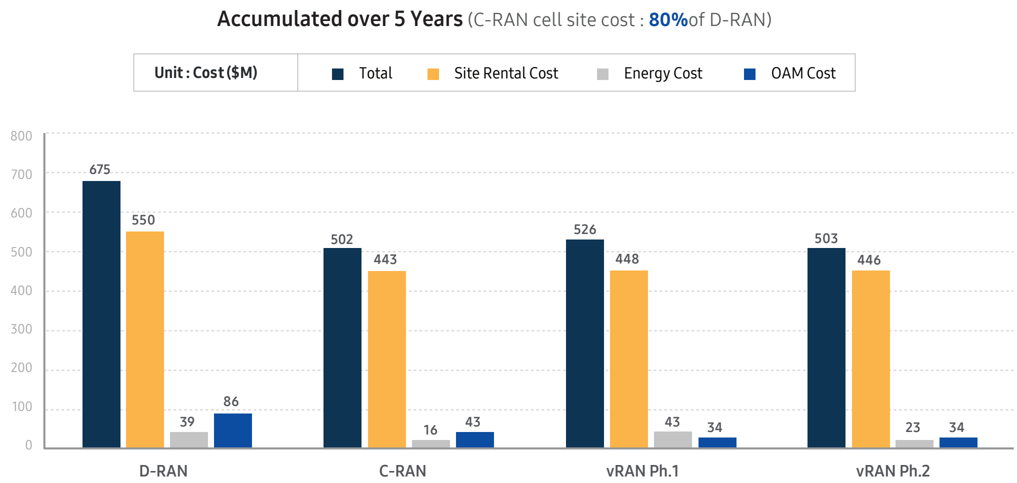


Relatively higher switching cost for C-RAN/vRAN is due to the required high-bandwidth optic modules and the number of ports in aggregation sites: In other words, 25GE link is enough per D-RAN site, but 100GE link is required per C-RAN/vRAN site given the reference cell configurations. This result implies that Transport cost optimization can only be achieved with the proper selection of the fronthaul function split options, whose TCO sensitivity analysis will be presented later.

3.2 OPEX DECOMPOSITION

In this study, OPEX costs are further decomposed into their respective components, as shown in Figure 3-3.

Figure 3-3 : OPEX Cost Decomposition



OPEX costs are decomposed into their respective components: site rental cost, energy cost and OAM cost, as shown in Figure1-7.

C-RAN/vRAN has about 25% lower OPEX compared to D-RAN by the benefits of centralization and virtualization.

The cell site rental cost is the largest part, comprising about 70~80% of the OPEX and this cost is expected to be reduced by about 20% in C-RAN architecture because cell floor space cost for DU is removed.

The energy cost consists of power consumption of DU and air-conditioning & rectifier of baseband. In C-RAN architecture, power consumption of air-conditioning & rectifier of basedband is removed at a cell site and power consumption of DU is optimized by pooling in centralized site. Accordingly, C-RAN/vRAN architecture achieves about 40% lower energy cost compared to D-RAN. (In this analysis, the power consumption of Radio and the power consumption of air-conditioning & rectifier for Radio are not included.)

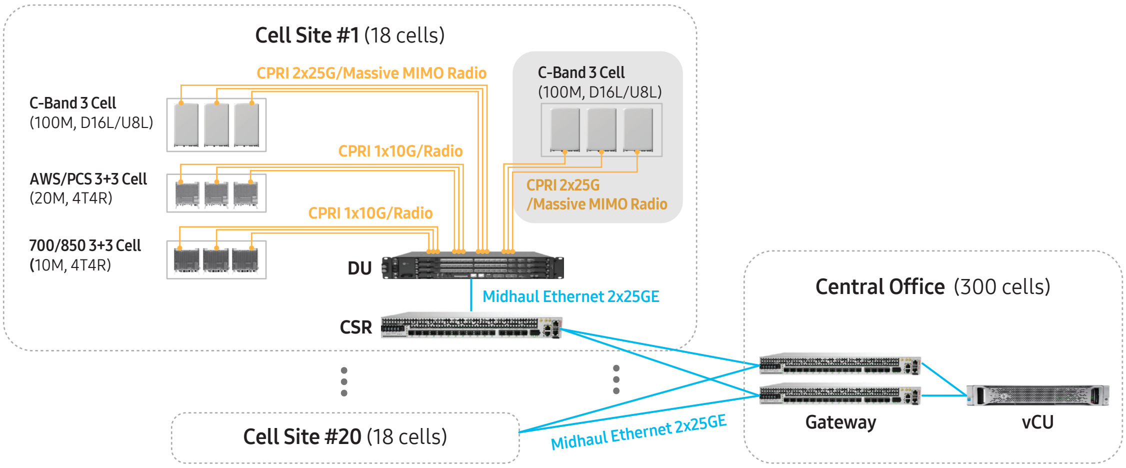
The OAM cost consists of HW and SW maintenance fee, site visit for baseband capacity upgrade, network fault management, radio performance optimization, SW upgrade, etc. C-RAN/vRAN architecture can reduce OAM cost by several factors such as: (i) very low site visit cost for baseband capacity upgrade; (ii) the removal of baseband HW maintenance cost; (iii) automation of OAM work such as SW maintenance, SW upgrade, fault management, and performance optimization. The OAM cost of C-RAN/vRAN is assumed as 40% of D-RAN/DU (50% by centralization effect in C-RAN, +20% by automated management of virtualized RAN).

3.3 IMPACT OF CELL DENSITIFICATION

It is generally understood that the D-RAN transport bandwidth requirement is less sensitive to the cell densification due to its relative small amount of additional midhaul bandwidth requirement, proportional to the cell peak or average throughput. What follows is a validation of the transport cost change when adding additional 3 sectors in the same site.

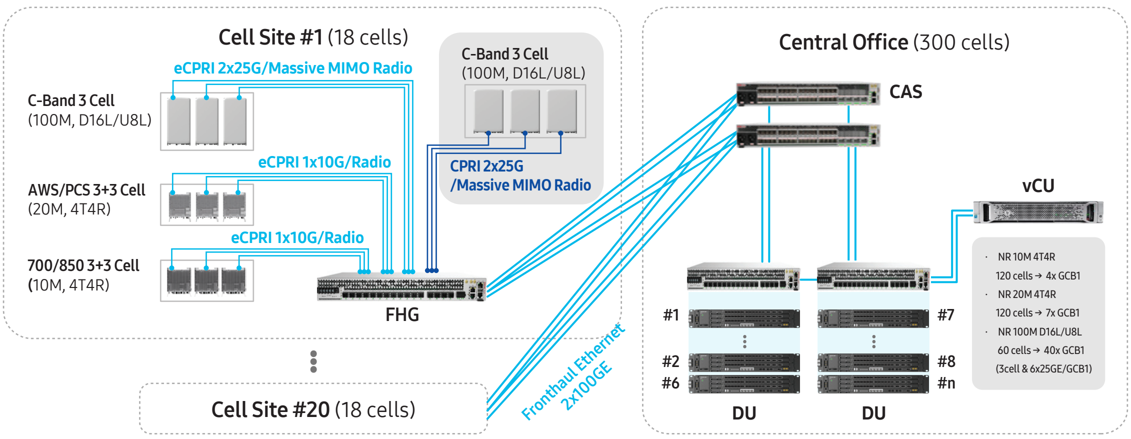
In the following sensitivity study, additional C-band 3 sectors is installed in the network to cover the increased traffic demand in the site. In D-RAN, this requires additional 10Gbps of transport bandwidth demand. However, this additional bandwidth demand is accommodated within the existing 1+1 25GE links, thereby incurring no additional transport cost (2x 25GE as shown in Figure 3-4)

Figure 3-4 : Cell Densification Example in D-RAN



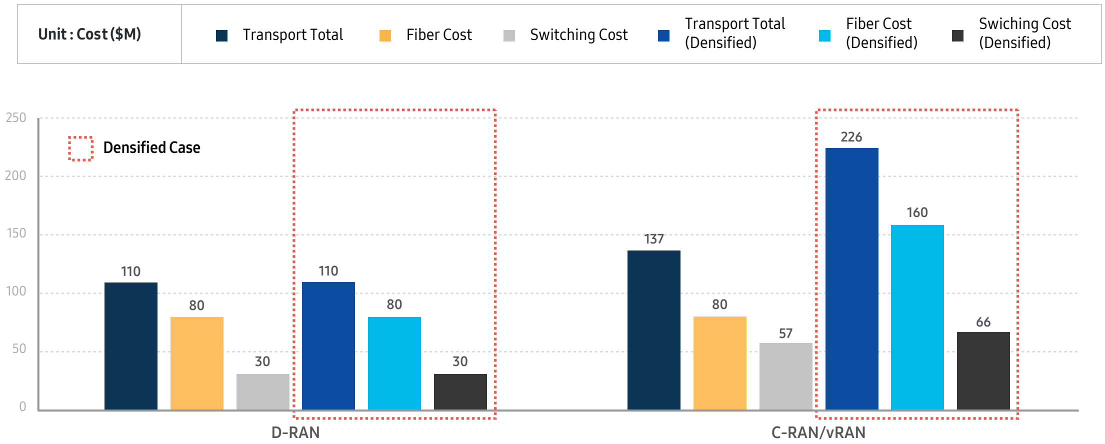
Unlike D-RAN, in C-RAN or vRAN, additional transport bandwidth requirement for the eCPRI function split Opt. 7-2x is 61.6Gbps as shown in Table 2-5. Thus, additional 100GE links need to be installed, and thus it ends up with doubling the existing transport costs (4x 100GE as shown in Figure 3-5)

Figure 3-5 : Cell Densification Example in C-RAN



The resultant TCO with cell densification is shown in Figure 3-6. Note that the following figure just shows a particular example of D-RAN transport cost being less impacted with the increase of bandwidth caused by cell densification than C-RAN/vRAN. It is possible to have other cell densification cases without additional transport cost increase from the existing C-RAN baseline cost; e.g., low-band 700/850 cell densification in the example network configuration. Thus, transport cost vs. cell densification should be evaluated case-by-case.

Figure 3-6 : Comparison of Transport Costs: Normal vs. Densified cases



SUMMARY AND CONCLUSION

VRAN is a new architecture enhancing the flexibility of C-RAN by virtualizing the functions of basebands in a common resource pool made up of the COTS servers located in centralized hub, allocating resources in a flexible manner according to traffic conditions.

Among the key value propositions of vRAN identified in this document are:

- Flexible and adaptive capacity management via resource pooling and workload placement
- Lower total cost of ownership with unified hardware and software infrastructure
- Simplified network operation and maintenance through unified management
- Foundation for automated network slicing through dynamic resource scaling and function instantiation
- Enabling operation and service innovation using unified infrastructure and management

vRAN based on Centralized RAN deployment is a more economical architecture than D-RAN with an overall TCO reduction by 13% and an overall OPEX reduction by about 25% for the cumulated 5 years.

The primary contributing factor for CAPEX reduction with vRAN among others is the rental cost of dark fibers. The primary contributing factors for the OPEX reduction are the site rental cost followed by the energy cost.

Since the C-RAN/vRAN's cell site rental cost is lower than D-RAN, it significantly affects reducing TCO in vRAN than in D-RAN. If the cell site rental cost of vRAN in a real network is lower than our assumption (80% of D-RAN in this document), the TCO saving effect will be greater.

The energy cost in C-RAN/vRAN is saved up to about 40% due to the elimination of air conditional & rectifier power consumption for baseband in a cell site, COTS HW performance upgrade and resource pooling. The energy saving effect can be further increased by improving resource utilization using Cloud Native virtualization technology. Cloud Native virtualization allows a more effective and flexible scaling mechanism (scale in/out, up/down) in which to change resources required per daily traffic load fluctuation (e.g., by day or night), or special event, etc.

The dark fiber rental cost is the major cost factor of transport CAPEX and it can be more impacted in vRAN architecture with the increase of bandwidth by cell densification due to high bandwidth in a fronthaul. Therefore, in vRAN architecture with highly dense cell concentration, higher bandwidth optics/ports (200GE, 400GE) above 100GE would have to be considered in order to reduce the number of required dark fibers. Technology like WDM might also be considered to be able to send multiple optical channels over the single fiber as a way to reduce fiber cost at the expense of WDM cost.

Baseband pooling gain in vRAN architecture depends on cell density at cell site (that is, number of cells per cell site) and baseband pool size (that is, number of cells per C-RAN hub site). In case of this TCO model with typical cell configuration (e.g., average 10~15 cells per cell site, based on 4T4R 4L 20MHz bandwidth), there are baseband pooling gain by about 30%.

Even though current vRAN solution (vRAN phase1) has higher initial deployment cost than DU, vRAN is a more economical deployment option for deploying new 5G network or replacing legacy 2G/3G/4G, since vRAN provides a lower 5-year TCO and additional value propositions enabling technologies (such as network slicing, edge computing, automation, cloud native) essentially needed for transition to 5G.

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