Guidelines for a cost optimised 5G WDM-based Fronthaul network

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Abstract *We evaluate the total cost of ownership of key 5G Centralised Radio Access Network Fronthaul architectures to provide a methodology for operators to select the most cost optimized transport architectures.*

Introduction

5G Radio Access Network (RAN) has two deployment scenarios: Distributed Radio Access Network (D-RAN) architectures, where the Base Band Unit (BBU) is placed in very close proximity of the Remote Radio Unit (RRU); and Centralized Radio Access Network (C-RAN) architectures, in which the Baseband processing is centrally located in a Data Center or Central Office. Centralization of the Baseband processing offers multiple benefits for operators, including reduced site rental fees and maintenance costs and allowing an evolution towards a virtualized RAN architecture. Compared to DRAN, C-RAN architectures introduce new stringent technical requirements, such as ultra-low latency, increased bandwidth and more accurate synchronisation. Several standard defining organisations have proposed a number of architectures, from Passive xWDM to “Active Transparent”, or “Active Packetized” architectures to address these difficult C-RAN requirements[1][2][3] , but operators are still left with a considerable barrier of proving the business case for investment and deployment of Fronthaul networks. Previous publications have provided a Total Cost of Ownership analysis of various C-RAN related challenges , such as TCO analysis of C-RAN migration strategies [4] [5];and energy consumption based on simpler networks[6], but to date, a comparison between different C-RAN architectures has not been considered.

The aim of this paper is to examine the proposed Fronthaul Networking architectures from a TCO perspective, in order to provide the operator with guidelines to select the appropriate Fronthaul technology.

Network Architectures

In the following we describe the different C-RAN fronthaul architectures focusing on the case where fiber is a scarce resource and has a leasing cost, and where transport resilience is not required.

A. Passive WDM - This solution, illustrated in Fig.1 is based on an all-passive end-to-end connectivity, without optical amplification, dispersion compensation or optical-electrical-optical conversion (OEO). The coloured optical transceivers insert directly into the RRU at the cell sites, and into the baseband unit at the Central Office hub and connect at a local un-powered outdoor cabinet to a passive Optical Multiplexer/Demultiplexer. WDM-based systems, including Coarse wavelength division multiplexing (CWDM), Dense wavelength division multiplexing (DWDM) and other more recent schemes such as M-WDM are considered.

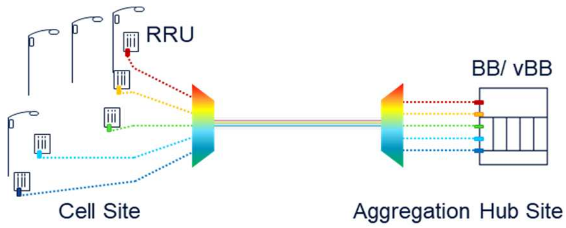

Fig. 1: Passive-passive Optical WDM Fronthaul network

B. Active-Active WDM – In this solution the RRUs connect using short reach (SR) optics to the active network elements at the cell and central sites. Two models of Active-Active architectures are possible: (1) Active Transparent architecture provides re-colouring of the interfaces from the RRU’s to WDM interfaces which are then optically multiplexed onto a single fiber (pair) towards the central site; and (2) Active Packet architecture, allows for common public radio interface[7] (CPRI) traffic Ethernet packetization and can further reduce the transport capacity through either a IEEE 1914.3 Radio over Ethernet Structure Aware mapping[8] that can remove un-used antenna carriers (AxC) in the CPRI stream, or through statistical multiplexing of the eCPRI stream[9].By reducing the transport capacity, lower cost 100Gbps grey optical transceivers can be used for the majority of sites, and 100Gbps DWDM Transceivers only when cell site capacity exceeds this. The Active Packet-based equipment at the cell site can use one of two form factors – A cabinet mounted 1RU

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pizza-box style unit or pole-mounted zero-footprint (ZFP) outdoor style unit.

Fig. 2 illustrates the different Active-Active packet-based architectures analysed in this study, including (i) and (ii) Packetized Transport with 100Gbps Grey optics in a cabinet (ZFP) form factor at Cell sites,(iii) and (iv) Packetized Transport with 100Gbps DWDM optics with cabinet (ZFP) form factor.

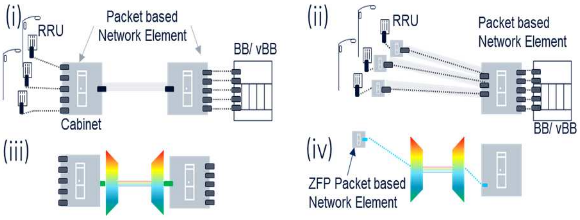

Fig. 2: Active-active Packetized Fronthaul network architectures

C. Semi-Active WDM - The semi-active or hybrid WDM solution is a simplification of the Active-Active WDM architecture and an enhancement of the Passive solution; a passive WDM solution is deployed at the remote Cell site, with an active-Transparent WDM solution at the aggregation site. As is illustrated in Fig. 3, the active WDM equipment at the central site provides translation of the WDM signals to Black & White or Grey signals towards the BB or the Data Center switching fabric.

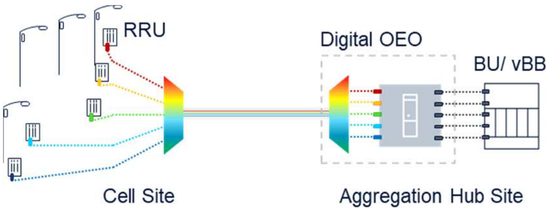

Fig. 3: Semi-active Optical WDM Fronthaul network

D. Active WDM Chains – these Active WDM architectures daisy-chain a number of ZFP cell sites before the aggregated traffic is sent to the BB Hub site. There are two solutions considered; (**I**) all connectivity is achieved via 100Gbps Grey optical interconnection, and (**II**) the aggregated traffic is using 100Gbps DWDM towards to hub while the intra-cell site connections are via Grey optics, as is illustrated in Fig.4.

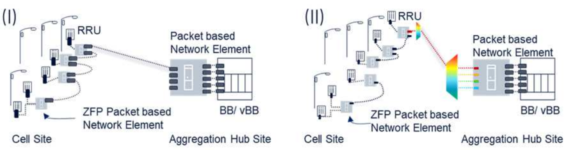

Fig. 4: Active Optical WDM Chain Fronthaul network

Study assumptions and Methodology

The TCO model considered a hub & spoke network topology consisting of a number of clusters of Cell sites, with spokes that connected to a central aggregation Hub site over a 10km optical link. Each cell site contained a number of 4G and 5G Radios with CPRI and eCPRI interfaces respectively with a user configurable number and relative mix between the two protocols. The clusters were multiplexed at a local central point in a cabinet at each Cluster.

For each of the above-described architectures, the Capital expenditure (Capex), including items such as the component and/or equipment costs at Cell and Hub sites, and operational expenditure (Opex) over a 5 year period, such as fiber leasing costs and remote site power, maintenance and cabinet costs, was calculated to provide a total solution cost for each architecture. This was then normalized to a Solution cost per cell site by dividing by the number of Cell sites in the model.

To fully explore the possible C-RAN deployment space, the normalized solution cost per cell site was calculated as a function of both (1) number of ports per Cell site and (2) number of Cell sites per Cluster. The results were further processed to select the lowest cost architecture at each of the points in this matrix and presented in a Heat-map as shown below.

Model Parameters

Table 1 summarises the cell site and hub site parameters per architecture with relative costs for Optical Transceivers (normalized to the DWDM Transceiver costs), Optical Mux/DeMux and Active Units.

Table 1: Model cost and equipment assumptions

<table>
<tr><td colspan="4" rowspan="2"></td><td rowspan="2">Passive</td><td rowspan="2">Semi-Passive</td><td colspan="3">Active</td></tr>
<tr><td>Active Transparent</td><td colspan="2">Active Packet</td></tr>
<tr><td rowspan="9">Optical Transceivers</td><td>xWDM</td><td>Bit Rate</td><td>Max λ count</td><td colspan="5">Relative Cost</td></tr>
<tr><td rowspan="2">CWDM</td><td>10G</td><td>18</td><td colspan="3">0,3</td><td colspan="2" rowspan="6"></td></tr>
<tr><td>25G</td><td>6</td><td colspan="3">0,3</td></tr>
<tr><td rowspan="2">MWDM</td><td>10G</td><td rowspan="2">12</td><td colspan="3">0,4</td></tr>
<tr><td>25G</td><td colspan="3">0,4</td></tr>
<tr><td rowspan="2">DWDM</td><td>10G</td><td rowspan="2">40</td><td colspan="3">1</td></tr>
<tr><td>25G</td><td colspan="3">1</td></tr>
<tr><td>Grey</td><td>100G</td><td>1</td><td colspan="3" rowspan="2"></td><td colspan="2">0,3</td></tr>
<tr><td>DWDM</td><td>100G</td><td>40</td><td colspan="2">1</td></tr>
<tr><td rowspan="3">Optical Mux/DMux</td><td colspan="2">CWDM</td><td>6</td><td colspan="3">0,33</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2">MWDM</td><td>12</td><td colspan="3">0,5</td></tr>
<tr><td colspan="2">DWDM</td><td>40</td><td colspan="5">1</td></tr>
<tr><td rowspan="9">Active Unit</td><td colspan="3">Form Factor</td><td rowspan="9"></td><td>Rack</td><td>Cabinet</td><td>Cabinet</td><td>ZFP</td></tr>
<tr><td colspan="3">Relative Cost</td><td>0,6</td><td>0,6</td><td>1</td><td>0,75</td></tr>
<tr><td colspan="3"># Client Ports</td><td>12</td><td>12</td><td>24</td><td>12</td></tr>
<tr><td colspan="3">Client port rates</td><td>10G, 25G</td><td>10G, 25G</td><td>10G, 25G</td><td>10G, 25G</td></tr>
<tr><td colspan="3"># Line ports</td><td>12</td><td>12</td><td>4</td><td>2</td></tr>
<tr><td colspan="3">Line port rates</td><td>10G, 25G</td><td>10G, 25G</td><td>100G</td><td>100G</td></tr>
<tr><td colspan="3">CPRI Processing</td><td>3R</td><td>3R</td><td colspan="2">IEEE1914.3 RoE Structure Agnostic</td></tr>
<tr><td colspan="3">eCPRI Processing</td><td>3R</td><td>3R</td><td colspan="2">Ethernet switching. Oversubscription =0.25</td></tr>
</table>

The operational cost assumptions over a 5-year period is provided in Table 2. Outdoor cabinet costs include site license, equipment (fans, battery backup, etc) and maintenance with an average energy cost of 0.1319 $/kWhr.

Table 2: Operational cost assumptions

		Fixed	Per unit
Operational costs (over 5 years)	Fiber lease cost (5 year lease) ($/month/km/fiber pair)	$50	
	Outdoor Cell site cabinet cost	$18 000	$1 400
	ZFP per unit power cost		$1 400
	Energy cost ($/kWhr)	0,1319	

Results

Using the parameters from Tables 1 and 2, a fixed traffic mix (3 x CPRI + 9 x eCPRI), and a fiber lease cost of $50/month/km/fiber pair the following results were obtained and illustrated in Fig. 5. This shows an example of the intermediate results, depicting the evolution of solution cost per cell site as the number of ports for each Cell site is increased, for a given number of Cell sites per Cluster.

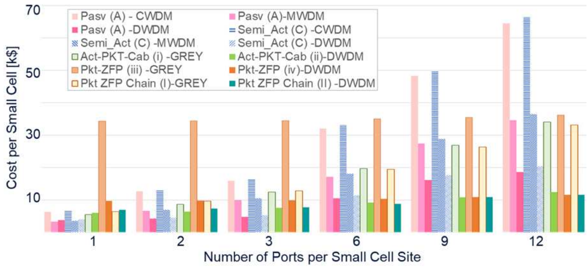

Fig. 5: Solution cost per cell site as a function of port count.

The lowest cost architecture for each port count/Cell count per Cluster was derived and presented in Fig 6. with a colour code as shown in the legend on the lower right of Fig 6. This shows the lowest cost architectures for, (A) Passive-only, (B) Active-only and (C) All architectures.

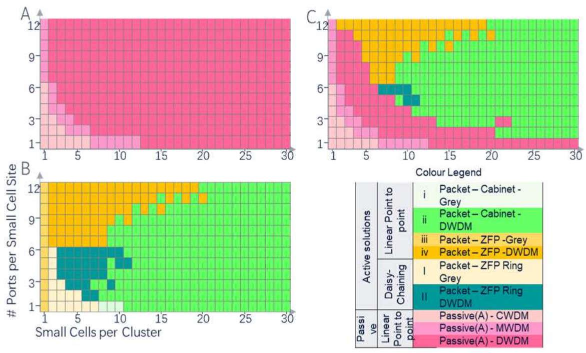

Fig. 6: Lowest TCO Heat map for (A) Passive-only, (B) Active-only, (C) Passive and Active architectures.

Discussion

Referring to the Fig 6. Passive-only analysis, the region of lowest cost of CWDM, MWDM and DWDM can be observed – directly related to the wavelength count in the fiber. This result is not surprising given that the three WDM technologies have been deliberately developed by the industry, to target this cost vs capacity trade-off.

Referring to the Active-only analysis, a number of regions can be observed. For low Cell sites per cluster, below approximately 10, ZFP architectures are the most cost effective. This is due to the relatively high cost of the powered cabinet required to house the remote Active unit, amortized over the low number of Cells. Within this region, for low number of ports per Cell, it is observed that ZFP chained architectures are the most cost effective, due to the benefit of aggregation of the per-cell traffic onto fewer Network interfaces. When capacity per cell is too large, the benefit of chaining diminishes, and a ZFP DWDM architecture is superior. For larger number of Cell sites per Cluster, the value of an Active-Packet cabinet-based solution can be seen, in which the statistical multiplexing from the large number of Cells, reduces the transport bandwidth and overall cost points.

Finally, combining all architectures, shows the region where Passive architectures are more cost effective, relative to Active Architectures.

Future work will explore the TCO impact of a Cell site Active unit to adapt CPRI to eCPRI in order to reduce the Transport bandwidth, as well as the inclusion of Access Transport resiliency models for the Ultra-reliable Low Latency Communication (urLLC) Use cases that will demand them in the future.

Conclusions

We have developed an analysis tool and methodology to compare the various Fronthaul architectures from a TCO perspective, allowing an operator’s specific conditions and roll out strategy for 5G to be used to determine optimum cost effectiveness in the Fronthaul. The benefits of the Active solutions are evident, in particular, where the statistical multiplexing gain from a large number of Cells can significantly reduce the Transport bandwidth. However, the burden of a powered location for the Active equipment can be significant and leads to a Passive or Semi-Active solution being more cost effective, especially when the number of Cells per cluster, and/or fibre lease costs are low. The results shown here were derived for a given set of assumptions, but it is noted that in practice, these can change substantially from operator to operator and should be evaluated based on each operators’ specific conditions.

Acknowledgements

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