EXECUTIVE SUMMARY

Service providers worldwide are in a race to deploy 5G technology and services. To achieve the promise of greater speeds and capacity with 5G, operators will need to densify their networks, resulting in significant growth in the number of macro cells and small cells. To optimize the total cost of ownership (TCO) of the Radio Access Network (RAN), many service providers are planning to leverage C-RAN architectures that centralize baseband processing functionalities. This allows for a much more efficient utilization of baseband unit (BBU) resources and improves operational efficiency at cell sites. However, by moving process-intensive functions to an aggregation site, bandwidth and latency transport requirements will increase. To address these higher transport demands it is now possible to extend IP into the RAN network and implement Ethernet-based packet routing solutions for the fronthaul, which is the portion of the transport network connecting the remote radio head (RRH) at the cell tower with the BBU located at an aggregation site. Today, 4G fronthaul networks are typically implemented by dark fiber or WDM optical transport networks. Although these techniques meet transport requirements, they can be very expensive. With innovations in Ethernet silicon, it is now possible to implement fronthaul transport with end-to-end IP-MPLS routers. There are many benefits to implementing an IP solution, most notably the support for multiple services concurrently (wirelines and wireless) and x-Haul (2G, 3G, 4G, and 5G). In addition to the benefit of transport convergences, the IP transport also enable operators to leverage the latest innovations in network automation and orchestration and extensively deploy robust monitoring and network control.

This paper compares the IP routing fronthaul network with several optical alternatives and shows a TCO advantage of 65% over a ROADM network and 46% over an active point-to-point optical network. The IP router fronthaul network provides significantly more functionality at lower cost than the optical fronthaul networks that are predominately deployed today.

KEY FINDINGS

- C-RAN is becoming a more popular mobile architecture option as operators explore options to reduce cost of densification.
- Fronthaul networks connect RRH radios in cell sites with BBU/CU/DU units in central locations.
- End-to-end IP routers can provide fronthaul services with many advantages over optical fronthaul networks.
- IP fronthaul networks have a 65% TCO advantage over ROADM networks and a 46% TCO advantage over point-to-point active optical DWDM networks.

OVERVIEW OF C-RAN AND FRONTHAUL

The Radio Access Network (RAN) provides the radios, baseband units, and network connectivity to packet core and IMS controllers. It is the most expensive part of a mobile network because many cell sites are required to provide complete regional coverage. As service providers move to 5G radio technology the number of cell sites will increase. Consequently, network densification is required to satisfy performance requirements for 5G networks. Reducing CAPEX and OPEX in the RAN is the key to reducing network expenses and maintaining or improving profit margins for service providers as they fulfill their densification strategy.

An innovative approach to reducing RAN expenses is to deploy centralized RAN or Cloud-RAN (C-RAN) architectures. It was first introduced by China Mobile[1] in 2010 and has been implemented on a small scale by service providers around the world. The basic idea of the C-RAN is to split the radio into two components: the RRU (analog radio unit) and BBU (digital baseband unit). In 5G networks the BBU is split into two subcomponents: Central unit (CU) and distributed unit (DU). By splitting up the RRH, CU, and DU it is possible to centralize the BBU/CU/DU while the RRH remains on the cell towers. The RRH units are connected with the BBU/CU/DU units using CPRI, a digital interface for transmitting radio signals. There are several key reasons for centralization:

- BBU/CU/DU pooling allows more effective utilization of these resources, which allows for greater network scalability and lower CAPEX
- C-RAN architectures allow for BBU/CU/DU virtualization
- BBU maintenance is simpler with a significantly lower number of centralized aggregation sites as compared to large numbers of cell sites

Some of the key areas of C-RAN cost savings are:

- Reduces CAPEX and OPEX due to BBU/CU/DU pooling and virtualization
- Reduces truck rolls and maintenance OPEX in cell sites
- Decreases power consumption at cell sites
- Reduces facility leasing expenses at cell sites
- Allows for more sites for RRH deployment

As service providers gear up for 5G, network optimization and cost reduction are critical to long-term business success. C-RAN is a key element of network optimization.

C-RAN FRONTHAUL ARCHITECTURES

In a C-RAN environment it is necessary to implement a fronthaul transport network, which is defined as the network connecting the RRH radio unit in the base station with the BBU/CU/DU in a central location. Many C-RANs will be deployed in dense urban locations. In such cases, it is possible to use the C-RAN fronthaul network to provide additional Ethernet services to business and residential customers

[1] *C-RAN The Road Towards Green RAN*, China Mobile White Paper, https://pdfs.semanticscholar.org/eaa3/ca62c9d5653e4f2318aed9ddb8992a505d3c.pdf

collocated in buildings with cell sites. Therefore, the fronthaul network can serve dual purposes: 1) connectivity between RRH radios and centralized BBU/CU/DU and 2) Ethernet connectivity for business or residential CPE devices.

There are multiple approaches to building fronthaul networks, and this paper compares the various approaches and provides a total cost of ownership (TCO) comparison of each approach. There are five fronthaul architectures that are compared in this paper:

1. IP router fronthaul network
2. Optical fronthaul network with ROADMs
3. Optical fronthaul network with active point-to-point DWDM
4. Optical fronthaul network with passive point-to-point DWDM
5. Optical fronthaul network with passive point-to-point CWDM

IP Router Fronthaul

The IP router fronthaul network is depicted in Figure 1. This is a new approach to fronthaul that uses IP-MPLS transport end to end. The IP routers are specially designed for fronthaul with Common Public Radio Interface (CPRI) and Enhanced Common Public Radio Interface (eCPRI) interfaces to RRH. These are standard digital interfaces designed for connecting RRH radios with BBU/CU/DU digital signal processing units. In this approach, IP routers are located at cell sites and provide connectivity to RRH units and, in some cases, CPE devices providing business services. Cell site fronthaul routers are connected to central BBU/CU/DU locations using 100GE links over fiber. The key benefits of using routers for fronthaul are:

- Allows for end-to-end management and control
- Provides multi-service transport
- Supports legacy backhaul for 2G, 3G and 4G radios
- Enables flexible topologies: ring, PT-PT, tree
- Offers full monitoring and control of Layers 1−4
- Leverages automation and orchestration
- Supports a myriad of potential future IP based services
- Emphasizes that routers have a lower TCO than other active solutions

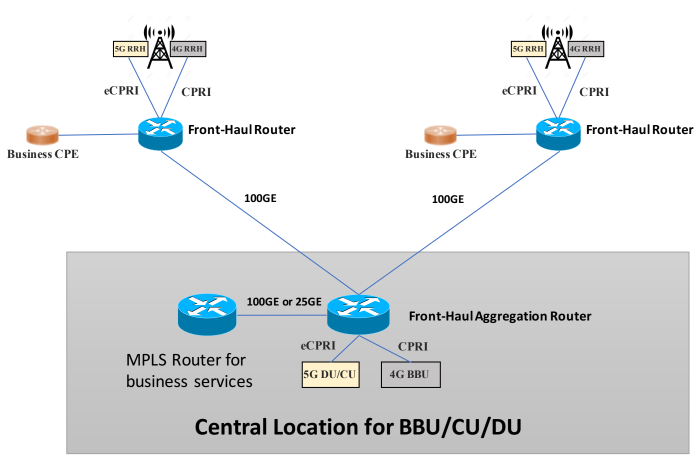

Figure 1. IP Router Fronthaul Network

Optical Fronthaul with ROADMs

Figure 2 depicts a fronthaul architecture that uses ROADMs in an optical network. The ROADMs have transponders with CPRI and eCPRI interfaces to RRH radio units. Business CPE can also be connected to the ROADM via Ethernet interfaces. The ROADMs provide high-capacity optical transport of CPRI and Ethernet traffic to the central sites. RRH radios connect with BBU/CU/DU units over DWDM.

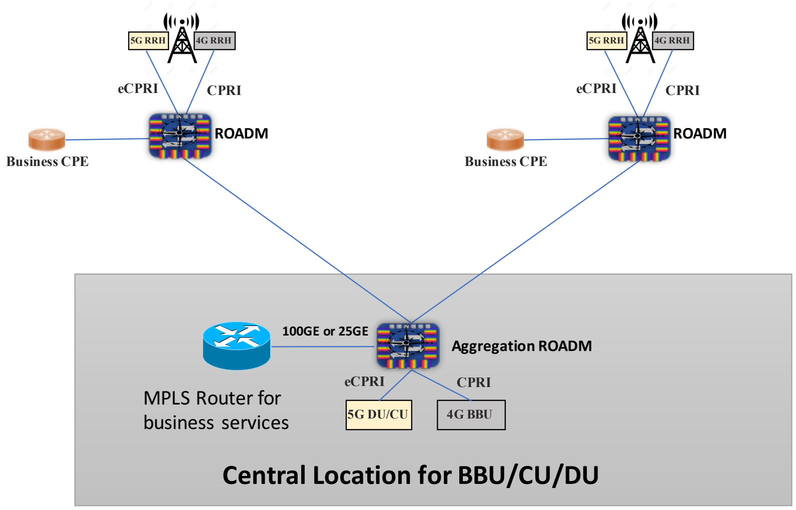

Figure 2. Optical Fronthaul with ROADMs

Optical Fronthaul with Active Point-to-Point DWDM

The ROADM network is flexible and scalable but also very expensive. A less expensive alternative considered in the analysis is an active point-to-point DWDM network, which is represented in Figure 3. This architecture only allows for point-to-point connections between the cell sites and central C-RAN sites. It allows for both monitoring and optical amplification, if necessary. In this architecture, the RRH units, CPE devices, and BBU/CU/DU units use DWDM colored pluggable optics at different wavelengths. The signals are multiplexed and de-multiplexed by passive DWDM MUX/DEMUX units and transmitted by active DWDM point-to-point transport systems.

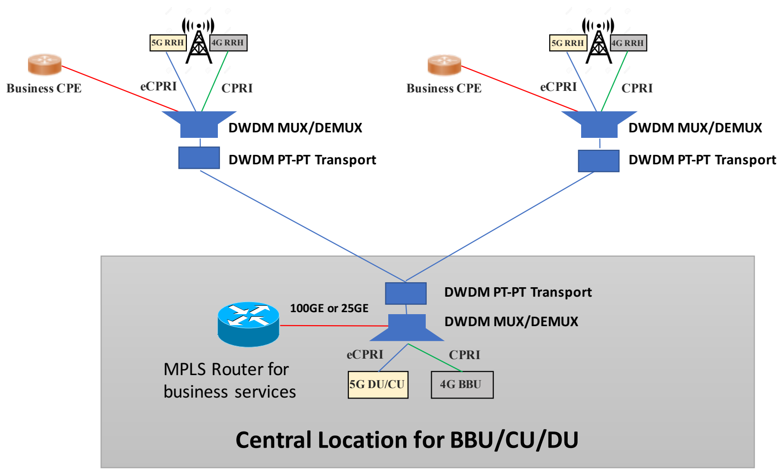

Figure 3. Optical Fronthaul with Active Point-Point DWDM

Optical Fronthaul with Passive Point-to-Point DWDM

A lower cost alternative for optical connectivity is a passive DWDM network represented in Figure 4. This approach is like the previous architecture; however, the active point-to-point DWDM transport nodes are removed. Because there are strict latency and distance requirements between the RRH and the BBU/CU/DU, there is usually no need for amplification. In the passive optical network, there is no monitoring of the optical signal, so any problems require truck-rolls to the cell sites for service. In both the active and passive architectures pluggable colored DWDM optics are used at all the end points.

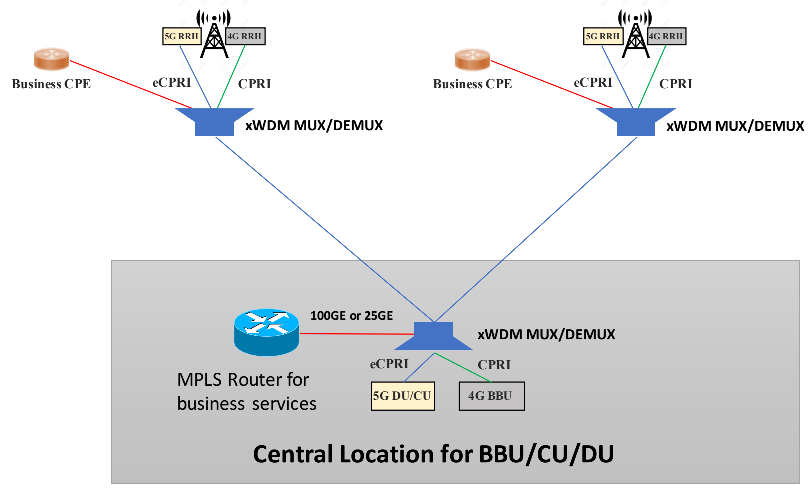

Figure 4. Optical Fronthaul with Passive Point-Point DWDM

Optical Fronthaul with Passive Point-to-Point CWDM

A less expensive optical alternative for connecting cell sites to C-RAN sites is passive CWDM. This alternative is also depicted in Figure 4. It is identical to the passive DWDM architecture with the exception that the MUX/DEMUX units are designed for CWDM and all the pluggable colored optics use CWDM. This also has disadvantages: lack of amplification, monitoring, and scalability. The functional limitations and lack of management controls cannot be entirely represented in a TCO model, but these disadvantages make this the least desirable approach to fronthaul. Furthermore, passive point-to-point optical networks cannot be modified without completely rebuilding the network.

Comparison of the Alternative Fronthaul Architectures

A comparison of the pros and cons of each of the fronthaul architectures is presented in Table 1. In the next section, we present a deep dive analysis of the TCO of each alternative.

Solution	PROS	CONS
IP Router Fronthaul	• End-to-end IP network • Multi-service network • Supports legacy backhaul • Flexible topologies, ring, PT–PT, tree • Full monitoring & control at Layers 1–4 • Automation & orchestration • Supports potential future	• New architecture for fronthaul that requires testing and training

	services • Lower TCO than all DWDM solutions	
ROADM	• High capacity optical network • Flexible topologies, ring, PT–PT, tree • Monitoring and control at Layer 1	• Highest cost • Layer 1 network, no visibility into Layers 2–4 • Complex network management and design
PT-PT Active DWDM	• Simple solution • High capacity • Monitoring and OAM at the optical layer	• Limited to PT-PT topology • Layer 1 network, no visibility into Layers 2–4 • Higher CAPEX than router solution with significantly less functionality
PT-PT Passive DWDM	• Simple solution • High capacity • Low cost	• Limited to PT–PT topology • Layer 1 network, no visibility into Layers 2–4 • No monitoring or OAM • Truck rolls are required for all maintenance and troubleshooting
PT-PT Passive CWDM	• Simple solution • Low cost	• Low capacity • Limited to PT-PT topology • Layer 1 network, no visibility into Layers 2–4 • No monitoring or OAM • Truck rolls are required for all maintenance and troubleshooting

Table 1. Comparison of Alternative Fronthaul Architectures

FRONTHAUL TCO ANALYSIS

To compare each of the fronthaul alternatives it is necessary to consider the total cost of ownership of each approach. The TCO includes CAPEX and OPEX. Service providers will need to evaluate the TCO of each alternative in conjunction with other attributes and benefits of the various solutions to make final decisions on the best approach for a given market.

TCO Model Assumptions

The TCO analysis compares the five alternative scenarios using a set of assumptions for network scale and traffic. The key assumptions are listed in Table 2.

Assumption	Value
# Cell Sites Connected to C-RAN Site	20
Number of C-RAN Sites	500
Total Cell Sites in Network	10,000
4G Average CPRI Traffic	1 Gbps
5G Average eCPRI Traffic	5 Gbps

Table 2. Key Network Scale and Traffic Assumptions

Additionally, assumptions for the number of CPRI, eCPRI, and CPE interfaces are presented in Table 3.

Interfaces per Cell Site	Year 1	Year 2	Year 3	Year 4	Year 5
CPRI Interfaces	9	9	9	9	9
eCPRI Interfaces	2	3	4	5	6
Enterprise Services	2	3	4	5	5

Table 3. Number of Interfaces per Cell Site

TCO Model Results

The five-year cumulative CAPEX, OPEX, and TCO for each of the five alternative architectures is presented in Table 4 and the savings of using a router architecture compared to the other alternatives is presented in Table 5. The key point is that the router architecture has the lowest CAPEX and TCO of all the alternatives. The OPEX of the CWDM network is higher than the passive DWDM network because additional fiber pairs are required that result in high fiber leasing expenses. Passive optical solutions are simple and require relatively low OPEX. However, the passive solutions require a larger number of truck-rolls because there is no monitoring capability at the nodes. The key conclusion from this analysis is that for service providers that want to build a highly functional, scalable, and adaptable fronthaul network, the IP router architecture is the best alternative with the lowest TCO.

Five-Year TCO Comparison	CAPEX	OPEX	TCO
IP Fronthaul Router-Based Solution	$217,850,000	$427,113,081	$644,963,081
ROADM-Based Solutions	$930,000,000	$931,622,007	$1,861,622,007
PT-PT Active Optical Solution	$618,520,000	$566,425,865	$1,184,945,865
PT-PT Passive Optical Solution	$566,000,000	$501,758,789	$1,067,758,789
PT-PT CWDM Passive Optical Solution	$220,000,000	$517,418,789	$737,418,789

Table 4. Five-Year Cumulative TCO Fronthaul Comparison

Five-Year Savings of Router Architecture	CAPEX	OPEX	TCO
ROADM	77%	54%	65%
PT-PT Active Optical	65%	25%	46%
PT-PT Passive Optical	62%	15%	40%
PT-PT CWDM Passive Optical	1%	17%	13%

Table 5. Five-Year Savings of Router Fronthaul Architecture

The five-year cumulative CAPEX, OPEX, and TCO comparisons are presented in Figures 5−7, respectively. The key point is that both the CAPEX and OPEX of the IP router solution is lower than all the other optical solutions, and the router network provides significantly higher levels of functionality than the optical networks.

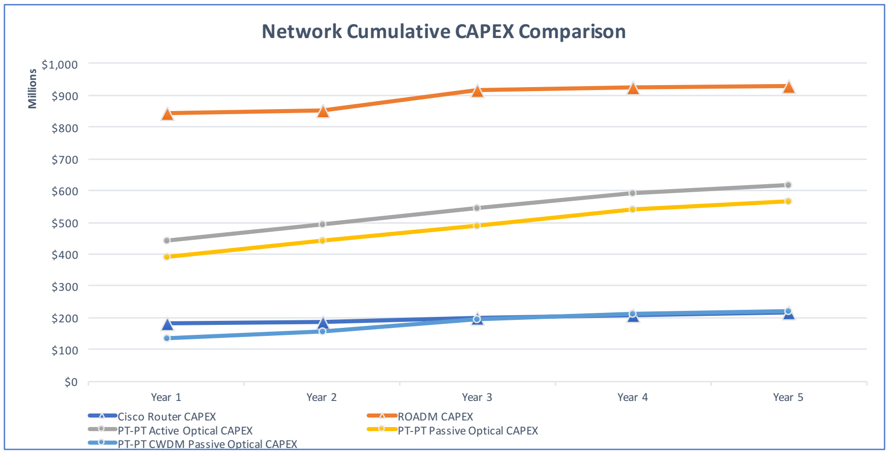

Figure 5. Five-Year Cumulative CAPEX Comparison

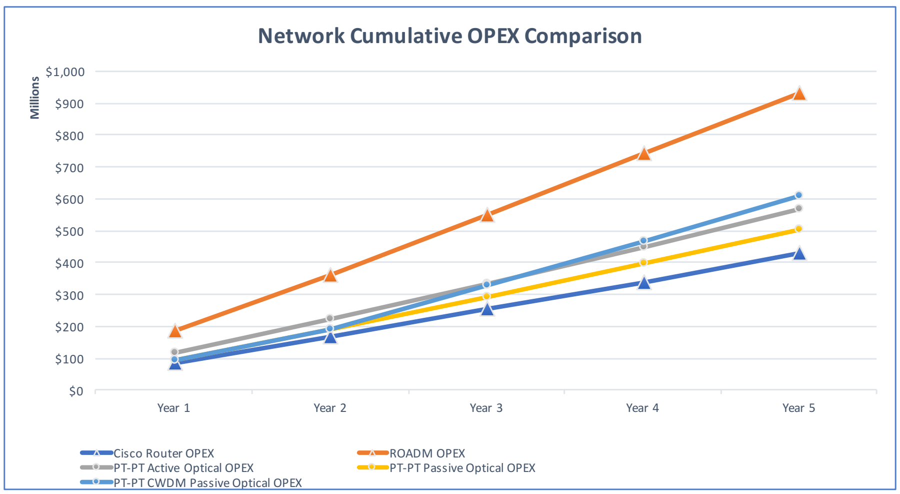

Figure 6. Five-Year Cumulative OPEX Comparison

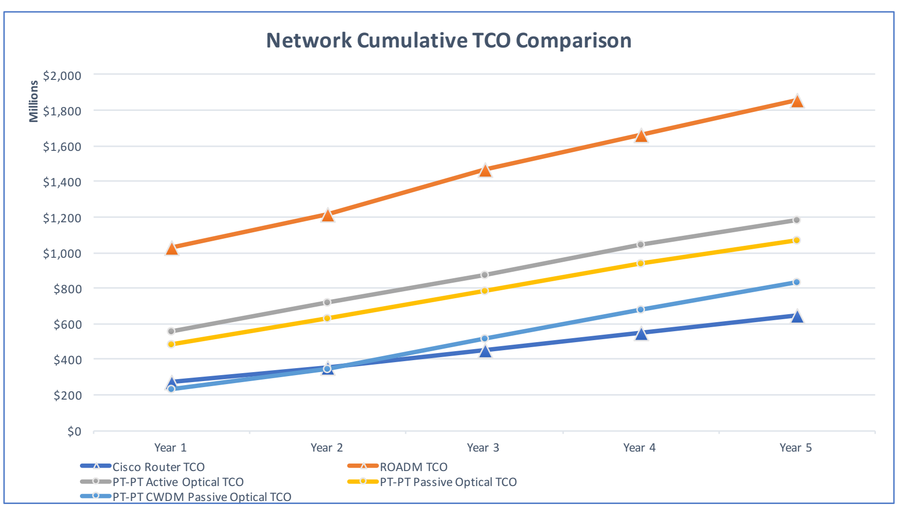

Figure 7. Five-Year Cumulative TCO Comparison

Power consumption in cell sites and C-RAN sites is an important variable. The cost of power and cooling is a significant component of OPEX, and power in cell sites is a limited resource. If power capacity is exceeded, it is extremely expensive and time consuming to upgrade the power distribution in a cell site. Figure 8 depicts the annual power consumption for each of the alternatives. It should be noted that the IP router solution is roughly equivalent with the active point-to-point optical approach and significantly lower than the ROADM network.

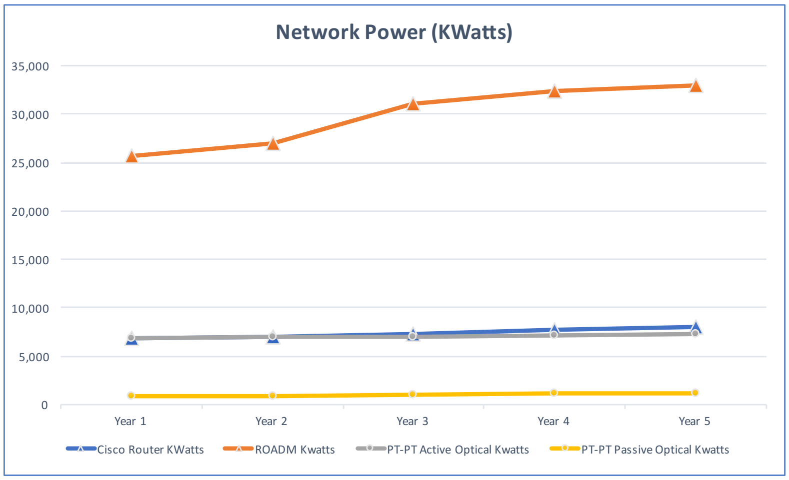

Figure 8. Annual Power Consumption Comparison

A five-year cumulative OPEX breakdown is presented in Figure 9. The IP router architecture is compared to the ROADM, point-to-point active DWDM, point-to-point passive DWDM, and point-to-point passive CWDM solutions. The passive solutions do not have any monitoring or control capabilities and require significantly more truck-rolls, because there is no visibility and any problems require a technician on site to diagnose and repair the equipment. The passive CWDM solution also has limited scalability because the MUX/DEMUX only supports 16 channels. In our model, network demand drives the need for more than 16 channels in Year 3. Therefore, an additional fiber pair needs to be added to each base station in Year 3, which results in additional fiber lease expenses for the CWDM solution.

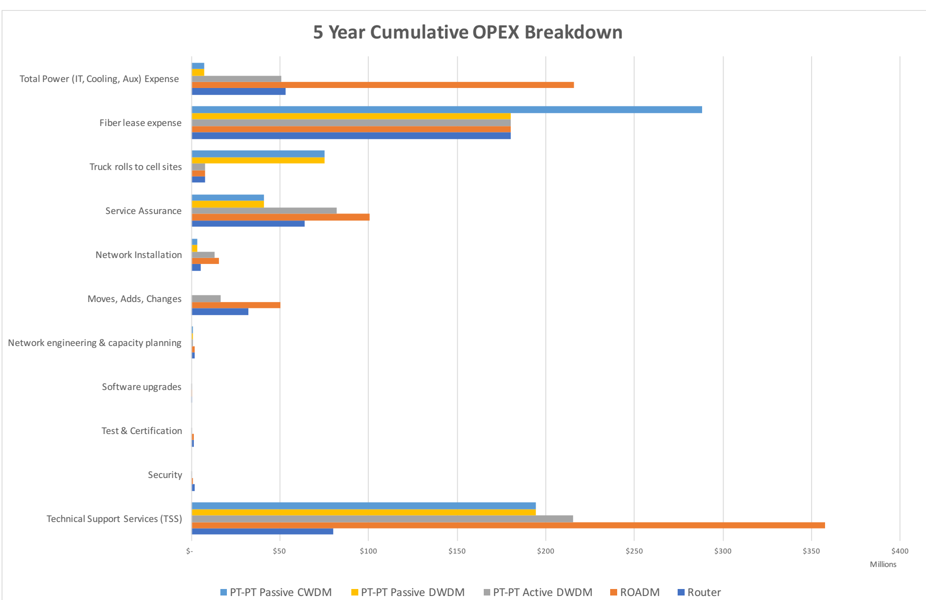

Figure 9. Five-Year Cumulative OPEX Breakdown

CONCLUSION

This paper proposes a new approach to fronthaul using IP routers with CPRI and eCPRI interfaces. An end-to-end IP network has many advantages over a Layer 1 optical network, including support for multiple services, backhaul for 2G, 3G and 4G radios, network automation and orchestration, flexible network topologies, and full monitoring and network control. We have compared the IP fronthaul solution to multiple optical network alternatives and found that the TCO of the IP fronthaul network is lower than all the other alternatives. Our conclusion is that service providers should consider deploying an intelligent and automated IP network for RAN fronthaul.

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