# Fiber- vs

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## Abstract

Answering a key question from operators, the paper compares the techno-economic performance of fiber and microwave-based 5G transport deployments using vendor's inventories and real-life field deployment scenarios. Results highlight how microwave gains vary based on the geo-types, the fiber trenching, and microwave equipment costs.

# Fiber- vs. Microwave-based 5G Transport: a Total Cost of Ownership Analysis

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**Abstract** Answering a key question from operators, the paper compares the techno-economic performance of fiber and microwave-based 5G transport deployments using vendor's inventories and real-life field deployment scenarios. Results highlight how microwave gains vary based on the geo-types, the fiber trenching, and microwave equipment costs. ©2022 The Author(s)

## Introduction

5G services have strict latency, throughput, and number of connected devices requirements. These services are enabled by novel radio technologies, efficient processing, and macrocells (MCs)/small cells (SCs) densification. However, cell densification requires the deployment of additional transport network (TN) equipment. Therefore, containing the total cost of ownership (TCO) of different technologies is of utmost importance for mobile network operators wanting to accelerate their 5G rollout. Optical fibers can carry a large amount of data. However, deploying fibers is a slow and expensive process, especially in sparsely populated areas. Compared to fiber, microwave-based TNs have a faster and easier rollout, making microwave an attractive option. Microwave is expected to remain the predominant backhaul media for MCs until 2025<sup>[1],[2]</sup>. However, the cost of the devices depends on transport requirements. Therefore, the cost-efficiency of microwave- vs. fiber-based TN deployments is impacted by the specific geo-type under exam (i.e., cell density, types, and inter-site distance).

This topic is not new in the literature. The work in<sup>[3]</sup> presented a framework for computing the TCO and net presented value of a 5G TN using fiber and microwave technologies in a dense urban area. The authors highlighted the importance of selecting the right technology and deployment strategy to maximize the economic benefits of an operator. On the other hand, they did not investigate different geo-types and how they can impact their conclusions. The authors in<sup>[4]</sup> estimated the TCO of deployments with a combination of wired and wireless backhaul options in three different cities. They found that microwave-based deployments always have lower costs. Still, they as-

sumed only a limited set of optical and microwave components and did not consider the latest 5G service requirements.

In this paper, we perform a TCO analysis of three architectures based on fiber and microwave technologies. We consider three different network deployment scenarios (dense urban, urban, and sub-urban). We also conduct a sensitivity analysis for the microwave devices and fiber trenching costs as they vary operator by operator and country by country<sup>[3],[5]–[7]</sup>. Based on the cost values obtained from conversations with a system vendor, the study shows how a microwave-based TN architecture shows good gains in terms of TCO. The exact amount depends on the geo-type under exam and the price range of fiber trenching and microwave equipment for the specific country/operator.

## Network and TCO modeling

The work assumes an early-stage 5G deployment with an Option 2 baseband functional split<sup>[9]-[11]</sup>. Most of the baseband processing functions run at the cell site, while the others are virtualized and placed in the central data centers (DCs). We consider three TN options connecting SCs/MCs to DCs (Fig. 1). Each option consists of an access and a metro segment. The metro segment is the same for all TN options where metro aggregation (MA) nodes are connected from one side to the backbone/core network and from the other to the metro segment(s) via pre-aggregation rings using the router and MUX/DeMUX devices. The MA nodes also host the DCs with the virtualized baseband processing units. The pre-aggregation rings connect the MAs to fiber aggregation (FA) nodes using passive distribution nodes (PDNs) (i.e., placed on the pre-aggregation ring) and optical add/drop multiplexers (OADMs) (i.e., at the



Fig. 1: F1, F2, and MW architectures for the access segment. The metro segment is common to all three.

FAs to add/drop wavelengths to/from the preaggregation ring). The FA nodes connect the metro to the access segment. We consider three architectural options for the access segment. The first is based on point-to-point optical fiber links (F1). The second uses a passive optical network (PON)-like structure (F2)<sup>[12]</sup>, while the third (MW) has a tree structure using microwave and mmWave band devices. The FA nodes are connected to MCs and SCs via one or two hops using fiber or microwave links, depending on the architectural option. Finally, the networking devices (NDs) are responsible for traffic grooming (i.e., multiplex low-rate into high-rate flows), link/network layer processing, and protection switching (i.e., between the FA - MA primary and secondary paths to protect against single failure on the ring).

The analysis considers three geo-types, i.e., dense urban, urban, and sub-urban. Each geotype has different values for the area extension, average link length, density of MCs/SCs, and traffic at an MC/SC. We compute the value of the aggregated traffic over a link in the access segment and over an FA-PDN link as  $R_{agg}(N) =$  $\max(R_{peak}, N \times R_{avg})^{[13],[14]}$ , where  $R_{peak}$  is the peak rate of an MC/SC at quiet times (i.e., when the cell serves the lowest number of users),  $R_{avg}$ is the average rate during busy hours, and Nis number of MCs and SCs sending traffic over the link under exam. The capital expenditure (CapEx) of F1, F2, and MW is computed by summing the cost of the equipment deployed in the access and metro segments (Tab. 1). The values reported in Tab. 1 are obtained from a systemvendor inventory. One cost unit [CU] is the market price of a 10G grey transceiver. When more options are available for a given microwave link, we choose the cheapest one able to meet the capacity and reach requirements. We assume trenching is needed for the fiber links in the access segment and the fiber links connecting an FA to a PDN. On the other hand, we assume that an operator can lease fibers for the pre-aggregation rings. The operational expenditure (OpEx) relative to one year of operations is computed as a percentage of CapEx, i.e., 5% of the total fiber deployment or microwave equipment cost plus 15% of the other CapEx contributors. The fees for using the microwave frequencies are included in the OpEx (i.e., 17.2 [CU] per microwave link).

#### **Results and Discussion**

This section presents a TCO analysis for the TN options described above. The TCO is computed over 5 years of operations. For each geo-type, i.e., dense urban (DUr), urban (Ur), and suburban (SUr), we assume the topology parameters values summarized in Tab. 2. The number of preaggregation rings is equal to the ratio between the total number of FAs and the number of FAs per pre-aggregation ring (rounded up to the next integer). The number of CPU cores required for baseband processing is as in<sup>[16]</sup>. Placing computing servers for baseband processing at the MA leads to 15% and 50% less server CapEx and OpEx, respectively, compared to when the same computing servers are placed at the cell site<sup>[4]</sup>.

Figure 2 presents the TCO breakdown. MW is more cost-effective than F1 and F2. In the access segment, the sum of microwave and optical devices cost (Ac-MW plus Ac-opt) in the MW option

Tab. 1: Cost in [CU]. The capacity of microwave devices is in Gbps.

Component	cost	Component	cost	Component	cost	Component	cost
10G-Eband 25G-Eband 50G-Dband 50G-Eband 75G-Multiband 100G-Dband 100G-Multiband	from 153 to 918.6	ND, 8×10G ports ND, 6×10G ports 4×(10/25G) ports leasing fiber [CU/m] fiber trenching [CU/m] colored 10G Tx/Rx colored 25G Tx/Rx	114.8 153.1 0.1 2.4 11 29.3	grey 10G Tx/Rx grey 25G Tx/Rx router port on MA server (8 cores) OADM (4CH) power splitter	1 2.2 95.7 127.6 98.5 19	fiber cable MUX (4CH) MUX (6CH) MUX (40CH)	Tab.1 <sup>[8]</sup> 69.8 75.6 119.7



is lower than the sum of the fiber deployment and the optical devices costs (Ac-fib plus Ac-opt) in the F1 and F2 architectures. The metro segment is the same for all architectures. As a result, the cost for the computing resources (i.e., Comp), the optical devices, and fiber deployment (i.e., Metopt and Met-fib) are the same. The TCO gain brought by MW varies with the geo-type. In urban and sub-urban areas, links are, on average, longer than in dense urban ones resulting in high fiber deployment costs in the access segment (Ac-fib). For this reason, MW has a larger TCO gain in urban and sub-urban areas. Figure 2 also shows that F1 and F2 have almost similar TCO performance. The cost values chosen for the fiber trenching and MW devices reported in Tab. 1 may vary depending on the country (e.g., higher/lower labor cost), the network operator (i.e., relationship with the vendors), and equipment order size (i.e., economies of scale). Figure 3 shows how TCO varies as a function of different fiber trenching costs and of different prices for the microwave devices (i.e.,  $\pm 20\%$  compared to the values in Tab. 1, BM in the figure). The MW gain in urban and sub-urban areas is not affected by different pricing of the microwave devices. On the other hand, in dense urban areas, the TCO performance of MW is more sensitive to the changes in the price values. For low fiber trenching costs and high costs of the microwave equipment, there might be instances where MW, F1, and F2 have similar TCO performance. On the other hand, an operator may still adopt MW due to the faster and less complex rollout.

## Conclusions

The paper presents a TCO analysis of a 5G TN using fiber and microwave-based architectures and deployed in different geo-types. In all the examined scenarios, the microwave-based architecture shows good advantages over its fiber-based counterparts. It was also found that in dense urban deployment the benefit of a microwave-based architecture might be sensitive to the variation of cost of fiber trenching and microwave equipment.

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**Tab. 2:** Network topology parameters.  $l_{av}$  is average link length [m],  $R_{peak}$  and  $R_{avg}$  are in [Gbps]<sup>[15]</sup>.

DI	Jr Ur	SUr		DUr	Ur	SUr		DUr	Ur	SUr
#PDN / pre-agg. ring5#FA / pre-agg. ring1MC: $R_{peak}, R_{avg}$ 10,SC: $R_{peak}, R_{avg}$ 10	5 6 2 14 10 10, 10 , 3 10, 3	7 16 5, 5 10, 3	#MA #FA #SC #MC	14 214 636 345	10 210 254 468	7 79 0 234	$l_{av}$ : PDN-PDN $l_{av}$ : FA-PDN $l_{av}$ : MC to MC/FA $l_{av}$ : SC to MC/FA	799 250 400 100	1098 350 600 200	1750 450 1000 400

#### References

- J. Saunders and N. Marshall, "Mobile backhaul options spectrum analysis and recommendations", ABI Research, Research Report, Sep. 2018.
- [2] T. Naveh, "Mobile backhaul: Fiber vs. microwave", Ceragon White Paper, vol. 1, pp. 1–11, Oct. 2009.
- [3] F. Yaghoubi, M. Mahloo, L. Wosinska, et al., "A technoeconomic framework for 5G transport networks", *IEEE Wireless Communications*, vol. 25, no. 5, pp. 56–63, 2018. DOI: 10.1109/MWC.2018.1700233.
- [4] H. Frank, R. S. Tessinari, Y. Zhang, et al., "Resource analysis and cost modeling for end-to-end 5G mobile networks", in *International IFIP Conference on Optical Network Design and Modeling*, Springer, 2019, pp. 492–503. DOI: 10.1007/978-3-030-38085-4\_42.
- [5] S. S. Jaffer, A. Hussain, M. A. Qureshi, J. Mirza, and K. K. Qureshi, "A low cost PON-FSO based fronthaul solution for 5G CRAN architecture", *Optical Fiber Technology*, vol. 63, May 2021. DOI: 10.1016/j.yofte. 2021.102500.
- [6] D. Ulloa, G. Arévalo, and R. Gaudino, "Optimal deployment of next-generation PON for high and ultra-high bandwidth demand scenarios in large urban areas", in 22nd International Conference on Transparent Optical Networks (ICTON), 2020, pp. 1–6. DOI: 10.1109/ ICTON51198.2020.9203528.
- [7] A. Mian and D. Reed, "Tomorrow's backhaul: Comparative analysis of backhaul cost for policy decisions", in *IEEE 5G World Forum (5GWF)*, 2018, pp. 123–128. DOI: 10.1109/5GWF.2018.8516937.
- [8] A. Udalcovs, M. Levantesi, P. Urban, et al., "Total cost of ownership of digital vs. analog radio-over-fiber architectures for 5G fronthauling", *IEEE Access*, vol. 8, pp. 223562–223573, 2020. DOI: 10.1109 / ACCESS. 2020.3044396.
- [9] Small Cell Forum, "Small cell virtualization functional splits and use cases", Tech. Rep., version 7.0, Jan. 2016.
- [10] 3GPP, "TR 38.801, study on new radio access technology: Radio access architecture and interfaces", Technical report, version 14.0.0, Mar. 2017.
- [11] 3GPP, "TS 38.470, F1 general aspects and principles", Technical specification, version 17.0.0, Apr. 2022.
- [12] J. S. Wey and J. Zhang, "Passive optical networks for 5G transport: Technology and standards", *Journal of Lightwave Technology*, vol. 37, no. 12, pp. 2830–2837, 2019. DOI: 10.1109/JLT.2018.2856828.
- [13] NGMN Alliance, "Guidelines for LTE backhaul traffic estimation", White paper, version 0.4.2, Jul. 2011.
- [14] ITU-T, "5G wireless fronthaul requirements in a passive optical network context", G-series Recommendations, Supplement 66, Sep. 2020.
- [15] O-RAN Open Xhaul Transport Working Group 9, "Xhaul transport requirements", Technical specification, version 1.00, Feb. 2021.
- [16] F. Z. Morais, G. M. de Almeida, L. Pinto, et al., PlaceRAN: Optimal placement of virtualized network functions in the next-generation radio access networks, 2021. [Online]. Available: https://arxiv.org/abs/ 2102.13192.