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

M. Lashgari[(1)], F. Tonini[(1)], M. Capacchione[(2)], L. Wosinska[(1)], G. Rigamonti[(2)], P. Monti[(1)]

[(1)] Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden,
maryaml@chalmers.se
[(2)] SIAE Microelettronica, Cologno Monzese, Italy.

Abstract *Answering a key question from operators, the paper compares the techno-economic perfor-mance 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 tech-nologies, efficient processing, and macrocells (MCs)/small cells (SCs) densification. However, cell densification requires the deployment of addi-tional transport network (TN) equipment. There-fore, containing the total cost of ownership (TCO) of different technologies is of utmost importance for mobile network operators wanting to acceler-ate 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[1],[2]. How-ever, the cost of the devices depends on trans-port 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[3] presented a framework for computing the TCO and net presented value of a 5G TN using fiber and microwave technologies in a dense ur-ban 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 investi-gate different geo-types and how they can impact their conclusions. The authors in[4] estimated the TCO of deployments with a combination of wired and wireless backhaul options in three different cities. They found that microwave-based deploy-ments 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 analy-sis for the microwave devices and fiber trenching costs as they vary operator by operator and coun-try by country[3],[5]–[7]. Based on the cost values obtained from conversations with a system ven-dor, the study shows how a microwave-based TN architecture shows good gains in terms of TCO. The exact amount depends on the geo-type un-der exam and the price range of fiber trenching and microwave equipment for the specific coun-try/operator.

Network and TCO modeling

The work assumes an early-stage 5G deployment with an Option 2 baseband functional split[9]–[11]. 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 ac-cess and a metro segment. The metro segment is the same for all TN options where metro aggre-gation (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 op-tical add/drop multiplexers (OADMs) (i.e., at the
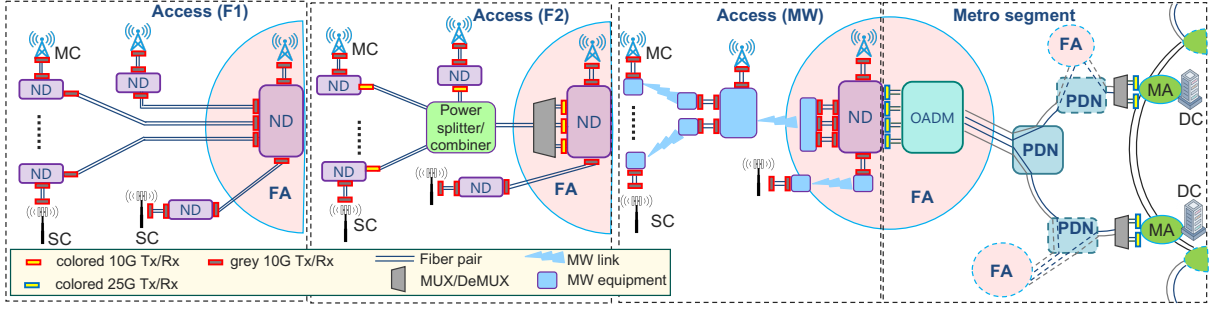
Fig. 1: F1, F2, and MW architectures for the access segment. The metro segment is common to all three.

FAs to add/drop wavelengths to/from the pre-aggregation 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)[12], 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 geo-type 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 N is 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 system-vendor 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 sub-urban (SUr), we assume the topology parameters values summarized in Tab. 2. The number of pre-aggregation 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[16]. 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[4].

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		ND, 8×10G ports	114.8	grey 10G Tx/Rx	1	fiber cable	Tab.1[8]
25G-Eband	from	ND, 6×10G ports	153.1	grey 25G Tx/Rx	2.2	MUX (4CH)	69.8
50G-Dband	153	4×(10/25G) ports		router port on MA	95.7	MUX (6CH)	75.6
50G-Eband	to	leasing fiber [CU/m]	0.1	server (8 cores)	127.6	MUX (40CH)	119.7
75G-Multiband	918.6	fiber trenching [CU/m]	2.4	OADM (4CH)	98.5		
100G-Dband		colored 10G Tx/Rx	11	power splitter	19		
100G-Multiband		colored 25G Tx/Rx	29.3				
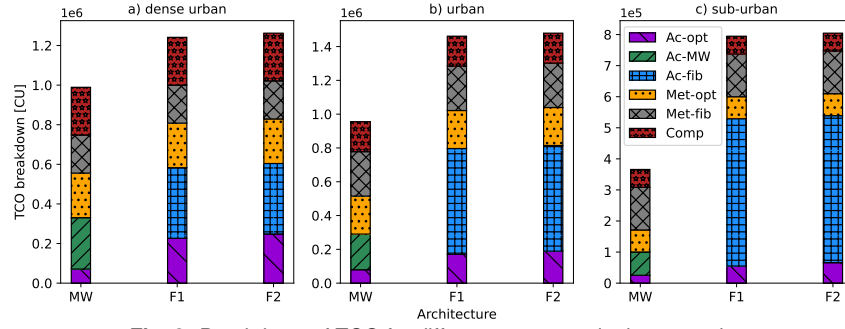
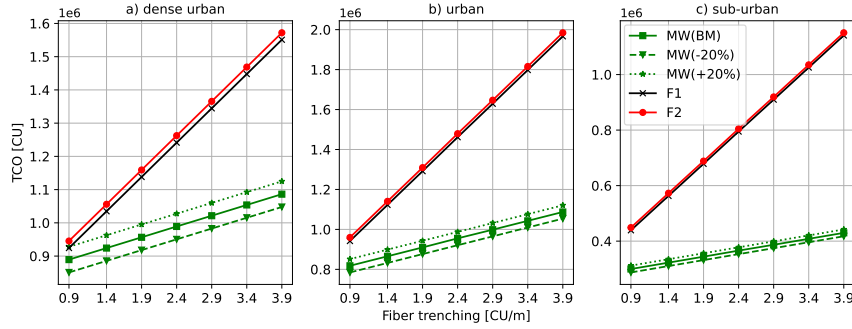**Fig. 2:** Breakdown of TCO for different geo-types in the network.

Fig. 3: TCO for different fiber trenching and microwave equipment cost values.

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., Met-opt 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., ±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.

Acknowledgments

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

	DUr	Ur	SUr		DUr	Ur	SUr		DUr	Ur	SUr
#PDN / pre-agg. ring	5	6	7	#MA	14	10	7	l_{av}: PDN-PDN	799	1098	1750
#FA / pre-agg. ring	12	14	16	#FA	214	210	79	l_{av}: FA-PDN	250	350	450
MC: R_{peak}, R_{avg}	10, 10	10, 10	5, 5	#SC	636	254	0	l_{av}: MC to MC/FA	400	600	1000
SC: R_{peak}, R_{avg}	10, 3	10, 3	10, 3	#MC	345	468	234	l_{av}: SC to MC/FA	100	200	400

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