CHALMERS
UNIVERSITY OF TECHNOLOGY

Techno-economics of 5G transport deployments

Citation for the original published paper (version of record):
Lashgari, M., Tonini, F., Capacchione, M. et al (2023). Techno-economics of 5G transport deployments. Proceedings of SPIE - The International Society for Optical Engineering, 12429. http://dx.doi.org/10.1117/12.2652618

Techno-economics of 5G transport deployments

Maryam Lashgari[a], Federico Tonini[a], Massimiliano Capacchione[b], Lena Wosinska[a], Gabriele Rigamonti[b], and Paolo Monti[a]

[a]Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden
[b]SIAE Microelettronica, Cologno Monzese, Italy

ABSTRACT

Network densification is a crucial enabler for 5G, requiring the installation of a large number of devices and/or cables for the 5G transport network. This invited paper provides a techno-economic study focusing on adopting microwave and fiber equipment for 5G transport network deployments. Different architectures for low layer split supporting latency critical services are considered.

Keywords: Techno-economics, 5G transport, network deployment, low latency services, low layer split, microwave, fiber.

1. INTRODUCTION

5G promises the delivery of services with unprecedented network capacity. To do so, operators are deploying a massive number of macrocells (MCs) and small cells (SCs). Purchasing, installing, and operating a network with such a large number of cells is costly. In addition, MCs and SCs require the deployment of transport network equipment to carry the traffic to/from users, which further increases costs. Recently, 5G standardization bodies introduced the possibility of virtualizing and centralizing part of the functions of the 5G protocol stack. This is done mainly to achieve better performance and cost savings[1]. There are several options for baseband functional splits, where the high layer split (HLS) and low layer split (LLS) are two extremes and correspond to the most distributed and most centralized options, respectively. They bring different implications for operators regarding bandwidth, latency, and, consequently, the cost of the transport network[2].

The HLS decouples the high-layer functions of the 5G protocol stack from the cell sites. As a result, the bandwidth requirement is in the order of a few Gbps per site depending on the capabilities of each MC and SC, while the latency requirement is in the millisecond range, and depends on the service. For the transport network, different technologies can be used, where microwave and fiber are the most used options[3]. In[4], we studied the total cost of ownership (TCO) implications of different microwave- and fiber-based architectures for HLS option in areas with different cell densities, showing how the microwave gains are impacted by fiber deployment and microwave equipment costs.

The LLS is another option for operators. In LLS, only a few low-layer functions of the 5G protocol stack are performed at the cell sites while the rest are centralized, achieving cost savings on compute resources and enabling efficient radio performance[5]. However, compared to its HLS counterpart, a LLS option is more demanding in terms of bandwidth and latency on the transport network[6]. The required bandwidth is in the order of tens of Gbps per site. The latency constraint depends on the specific class to be supported. It can be as low as 0.025 [ms] in the most extreme case, e.g., High25 class[7]. This has strong cost implications as more complex and expensive equipment must be deployed. The work in[8] compares the TCO of LLS and HLS, concluding that there is no clear winner as the TCO depends on the service to be provided. The work in[9] shows that a hybrid architecture based on microwave and fiber equipment is a cost-efficient deployment solution. We carried out an initial assessment of the performance provided by different microwave- and fiber-based architectures for LLS in[10]. Thanks to its

---

Further author information: (Send correspondence to tonini@chalmers.se)
M.L.,F.T.,L.W.,P.M.: E-mail: {maryaml,tonini,wosinska,mpaolo}@chalmers.se
M.C.,G.R.: E-mail: {Massimiliano.Capacchione,Gabriele.Rigamonti}@siaemic.com

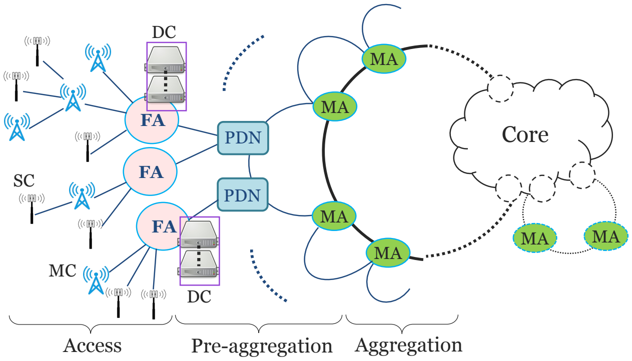


Figure 1: Example of general architecture[10].

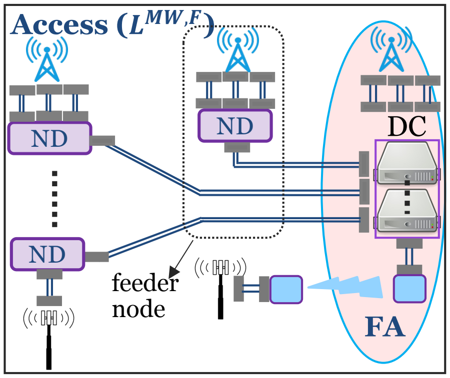


Figure 2: Hybrid fiber-microwave architecture in the access segment for low layer split.

large capacity and ultra-low latency, an optical network infrastructure is suitable to support highly demanding traffic. However, deploying fibers is expensive and characterized by slow rollout times. Microwave is a viable and cost-efficient alternative to fiber for enhanced mobile broadband (eMBB), URLLC-latency-tolerant (URLLC-T), and URLLC-latency-sensitive (URLLC-S) services. Only in the most extreme latency-critical scenario (i.e., URLLC-S), a small number of the cells might not fully satisfy the latency requirements of LLS for High25 class[7] due to multiple microwave hops.

In this paper, we focus on the transport network deployment of LLS to support URLLC-S services. We present a possible hybrid architecture in which fiber complements microwave to reduce delay for the sites where a microwave-based solution cannot meet the latency requirements. We compare this solution to the fiber- and microwave-based architectures proposed in[10] in terms of TCO and latency performance. Results for three different scenarios resembling different urban areas show that the presented hybrid architecture can alleviate latency issues of the critical sites while containing the costs compared to fiber-only-based solutions.

2. NETWORK ARCHITECTURES SUPPORTING LOW LAYER SPLIT

An example of a 5G transport network architecture is depicted in fig. 1. In this work, we focus on LLS option for 5G (e.g., option 7.2x defined in[6]). Users in a certain area are connected to MCs and SCs. The access network segment connects MCs and SCs to fiber aggregation (FA) nodes. They can be interconnected either via direct link or in a tree structure with a maximum of 2-hop distance. FA nodes are equipped with router ports, where MCs and SCs are connected to, and with compute resources (e.g., servers in a data center (DC)), that are used to perform virtualized baseband processing functions. FA nodes are connected to the core network via passive distribution nodes (PDNs) and rings of the pre-aggregation and aggregation network segments.

For the access segment, different architectural solutions based on fiber and microwave technologies can be used. Recently, we proposed a few architectures, which can be summarized as follows. More details on these architectures can be found in[10].

- **Point-to-point fiber-based architecture** (referred to as L_1^F) where MCs and SCs are connected to FA nodes via dedicated fiber connections and grey transceivers (Tx/Rxs).
- **Point-to-point fiber-based architecture with networking devices (NDs)** at the cell sites (referred to as L_2^F) to allow for aggregation of LLS traffic flows according to[11]. The NDs are then connected to FA nodes via dedicated fibers and grey Tx/Rxs.
- **Passive optical network (PON) like fiber-based architecture** (referred to as L_3^F) where signals from the cells are transported over different wavelengths employing colored Tx/Rxs. Signals can be aggregated/disaggregated by means of multiplexer (MUX)/de-multiplexer (DeMUX) and power splitters to reduce fiber usage. Instead, the MCs and SCs that are directly connected to FA nodes use (cheaper) grey Tx/Rxs.

- **Microwave-based architecture** (referred to as L^{MW}) where microwave and mmWave band devices are used to connect the MCs and SCs to FA nodes that are 1 or 2 hops away. In this architecture, fiber is used for the first hop from the FA nodes only when the aggregated traffic from MCs and SCs is larger than the maximum capacity of a single microwave device. Single MCs and SCs that are directly connected with 1 hop to FA nodes also employ microwave devices.

The evaluation of these architectures[10] highlighted that, in the case of URLLC-S and LLS, a small number of sites on microwave do not meet the strict latency requirements of URLLC-S (i.e., 0.025 $[ms]$). More specifically, this is the case of cell sites that are 2-hops away. Therefore, we present a new hybrid fiber-microwave architecture for LLS (referred to as $L^{MW,F}$), depicted in fig. 2. In this architecture, we connect the sites on the feeder node with fiber and grey Tx/Rxs to keep the latency to a minimum level for the tree structure. Conversely, the sites that are one hop away and directly connected to FA nodes leverage microwave and mmWave band devices. Similarly to L_2^F, NDs are deployed at cell sites[11].

3. PERFORMANCE METRICS

The architectures described in the previous section employ components with different characteristics and prices, possibly resulting in different transport network latency and cost values. Therefore, in this section, we describe the models for evaluating latency and TCO originally proposed in[10], that can be used to understand the advantages and limitations of each architecture.

3.1 Transport network latency

The network latency for each MC or SC is the sum of all the different contributors from the site to the FA node. Depending on the technology used in the transport network, different latency contributors can be identified. For fiber-based links, a delay is introduced by each ND traversed along the path (l_{ND}), if present, and the light propagation over the fiber per [km] (l_{fiber}). For microwave-based connections, propagation and processing delays are introduced by each traversed microwave link (l_{MW}). For each MC or SC, we can formally define the corresponding transport network latency for LLS as:

$$l_{\text{LLS}} = l_{\text{MW}} \times n_{\text{MW}} + l_{\text{fiber}} \times d_{\text{F}} + l_{\text{ND}} \times n_{\text{ND}}, \tag{1}$$

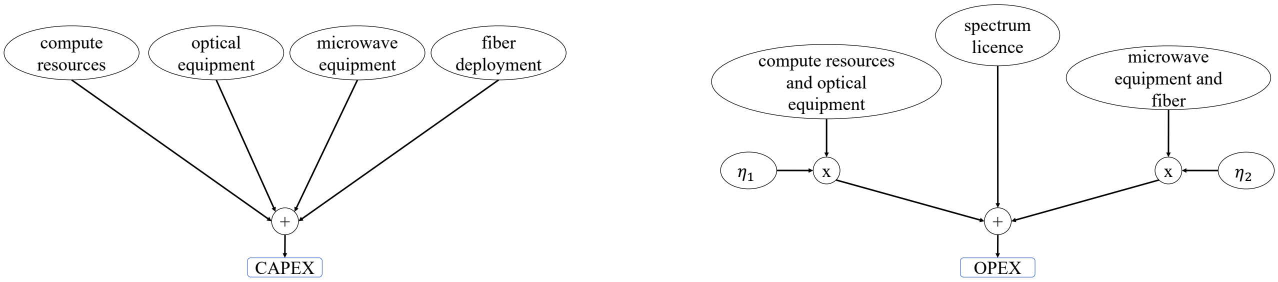
where n_{MW} and n_{ND} are the numbers of traversed microwave links and NDs, respectively, and d_{F} is the distance in $[km]$ traversed over fiber cables. Since l_{LLS} can be different for different MCs and SCs, we compute the percentage of sites ($P(L)$) able to meet the latency requirement (L)[10]:

$$P(L) = \frac{\#\text{sites with } l_{LLS} \leq L}{\text{total } \#\text{of sites}} \times 100, \tag{2}$$

where, l_{LLS} is computed using (1) for each site. $P(L)$ can be computed for each architecture and for different values of L to compare the performance.

3.2 Total cost of ownership

The TCO includes costs related to the network deployment and operation, which is calculated by summing the capital expenditure (CAPEX) and the operational expenditure (OPEX) of the network. The model adopted in this study is depicted in fig. 3. The CAPEX refers to all the expenses related to the design and creation of the network (fig. 3a). More specifically, we model this as the sum of the cost of compute resources in FA nodes and MCs/SCs, optical equipment (i.e., ND, MUX, Tx/Rx, splitters, router ports at FA nodes), microwave equipment, and fiber deployment (i.e., fiber trenching and cables)[10]. The OPEX (fig. 3b) accounts for all the expenses that occur during one year of network operation (e.g., electricity bills, and maintenance). More specifically, the OPEX is the sum of three terms. The first term represents the operational cost of compute resources and optical equipment. This term is assumed to be the sum of the CAPEX of compute resources and optical equipment multiplied by a factor η_1. The second term is the spectrum license fee for the microwave links. The third term represents the operational cost of microwave equipment and fiber, assumed to be the sum of the



(a) (b)

Figure 3: Cost modeling of CAPEX (a) and OPEX (b) used in this study.

CAPEX of the two multiplied by a factor η_2. The two factors η_1 and η_2 usually assume different values due to the different operational and maintenance costs of fiber and microwave compared to servers and optical devices. Finally, the TCO of each architecture is given by the sum of CAPEX and OPEX multiplied by the number of years the network operates.

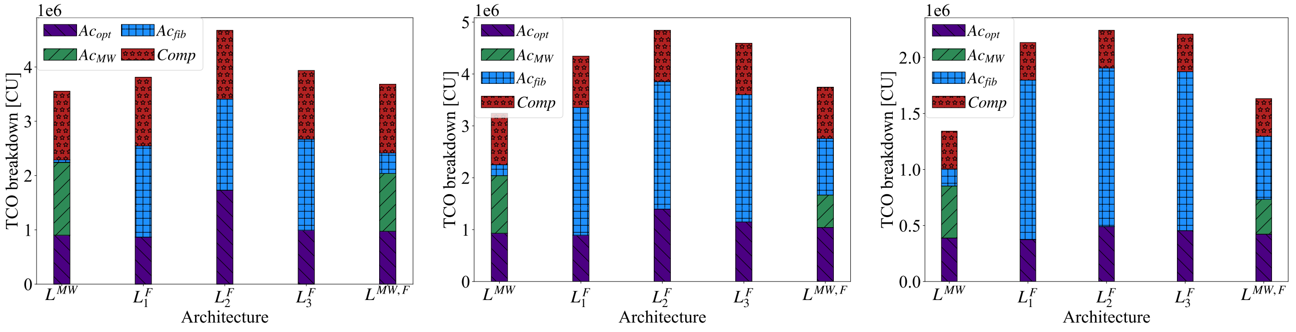
4. NUMERICAL RESULTS

4.1 Assumptions

In this study, we consider three different geo-types, namely dense urban, urban, and sub-urban. The numbers of FA nodes, SCs, and MCs for each geo-type are reported in tab.1. In the three scenarios, the distance MC-MC or MC-FA is assumed to be $400, 600, 1000$ $[m]$, respectively, while the distance SC-MC or SC-FA is assumed to be $100, 200, 400$ $[m]$, respectively[10]. We assume two types of cells. MCs are tri-sectorial antennas while SCs are simpler and have only one sector. The rate of each MC and SC is assumed to be 75 $[Gbps]$ and 25 $[Gbps]$, respectively[7]. The transport network latency requirement for LLS option depends on the service categories and is specified by the O-RAN Alliance[7]. In this work, we focus on URLLC-S. The LLS latency requirement for a URLLC-S service class is 0.025 $[ms]$. We assume that the latency introduced by a microwave link is 0.02 $[ms]$, the fiber propagation latency is 0.005 $[ms/km]$, and the delay introduced by an ND is 0.01 $[ms]$. All the costs for equipment, compute resources, fiber deployment, spectrum license, as well as η_1 and η_2 are set according to[10]. We extended the custom python-based simulator that we used in[10] to generate the new hybrid scenario and evaluate the performance. In the following, we compare the different architectures in terms of TCO and supported latency using the metrics explained in Section 3.

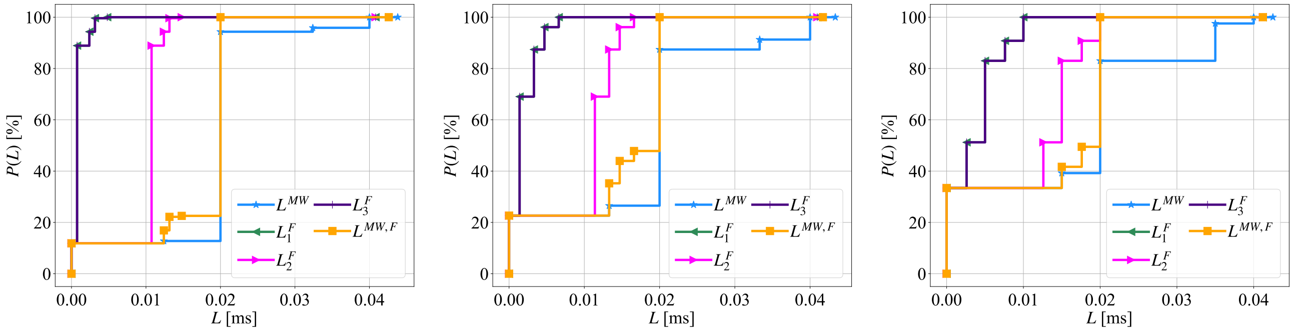
Table 1: Value of the network topology parameters considered in this study.

number of	dense urban	urban	sub-urban
FA	432	608	287
SC-1-hop	2811	1243	151
SC-2-hop	192	231	67
MC-0-hop	432	608	287
MC-1-hop	197	492	271
MC-2-hop	13	102	79
max. sites on feeder	3	4	5



(a) Dense urban area. (b) Urban area. (c) Sub-urban area.

Figure 4: The 5-years TCO comparison of the considered architectures supporting LLS in different areas. The four contributions (i.e., optical equipment (Ac_{opt}), microwave equipment including spectrum license (Ac_{MW}), fiber deployment (Ac_{fib}), and compute resources ($Comp$)) are shown.



(a) Dense urban area. (b) Urban area. (c) Sub-urban area.

Figure 5: The percentage of sites $P(L)$ that meet the latency requirement L for the considered architectures supporting LLS in different areas.

4.2 Evaluation results

Figure 4 shows the 5-year TCO breakdown for the considered architectures for LLS. The contributions of optical equipment (Ac_{opt}), microwave equipment including spectrum license (Ac_{MW}), fiber deployment (Ac_{fib}), and compute resources ($Comp$) are reported. In the dense urban area (fig. 4a), L^{MW}, L_1^F, and L_3^F provide similar costs, with similar contributions of Ac_{MW} and Ac_{fib}. This is mainly due to the short distances among sites in this scenario, which contains the fiber trenching costs, and the cost of complex and high-capacity MW equipment, which are balanced. The $L^{MW,F}$ hybrid architecture also exhibits similar costs. Finally, L_2^F exhibits higher cost, due to the large number of NDs in the network. In the urban area (fig. 4b) the cost differences among the architectures become more evident. In this scenario, $L^{MW,F}$, L_1^F, L_3^F, and L_2^F are respectively 16%, 34%, 42%, and 49% more expensive than L^{MW}. This is because distances among sites are larger than in the dense urban area, increasing the fiber deployment costs. This translates into a large contribution of Ac_{fib} to the TCO for the fiber architectures (i.e., 53% on average), making the use of microwave devices more cost-effective. The L^{MW} architecture, which employs microwave links in 73% of the sites, is the least expensive option. The $L^{MW,F}$ architecture instead, thanks to the use of microwave devices in 52% of the sites, is able to contain the costs compared to fiber-only-based architectures. These effects are even more evident in the sub-urban area (fig.4c), where distances are larger and Ac_{fib} contribution is around 65% of the TCO for the fiber-only-based architectures. In this scenario, $L^{MW,F}$, L_1^F, L_3^F, and L_2^F are 22%, 59%, 65%, and 67% more expensive than L^{MW} architecture, respectively.

Let us now focus on the latency performance of the considered architectures. Figures 5a, 5b, and 5c report the $P(L)$ for the different architectures in the dense urban, urban, and sub-urban areas, respectively. It is possible to observe that the requirement of a URLLC-S service, i.e., $L = 0.025$ $[ms]$ is not always met. In particular, the microwave-based architecture L^{MW} is not able to meet the requirement in $5.7\% - 17\%$ of the sites depending on the area. This is due to the delay introduced by each microwave link, which is 0.02 $[ms]$. This delay negatively affects the small number of sites located 2-hops away from FA nodes. The dense urban area is the least affected due to the lower percentage of sites that are 2-hops away, while the sub-urban area is the most affected. The $L^{MW,F}$ hybrid architecture instead is able to overcome this issue by covering sites that are on feeder with fiber. For this architecture, the worst experienced latency is 0.02 $[ms]$. Fiber-only-based architectures exhibit slightly better latency values.

5. CONCLUSION

This paper proposes a hybrid fiber-microwave architecture for a 5G transport network using LLS. We evaluate the architecture in terms of TCO and latency performance while providing URLLC-S services. For this service class, latency issues may arise on a few sites distant from FA nodes. In many practical cases, this small number is not an issue, as not all the sites are required to support latency-critical services. However, if providing URLLC-S service in 100% of the sites is imperative, a hybrid architecture can be adopted, taking advantage of the microwave links in the majority of the sites to reduce costs compared to fiber-only-based architectures. This behavior is more noticeable in urban and sub-urban areas, as costs for fiber-only-based architectures are mainly driven by fiber trenching over long(er) distances.

ACKNOWLEDGMENTS

This work was supported by the Smart City Concepts in Curitiba (2019-04893) project sponsored by VINNOVA (Sweden's innovation agency).

REFERENCES

[1] 3GPP, "TR 38.801, study on new radio access technology: Radio access architecture and interfaces," technical report (March 2017).

[2] Fiorani, M., Skubic, B., Mårtensson, J., Valcarenghi, L., Castoldi, P., Wosinska, L., and Monti, P., "On the design of 5G transport networks," *Photonic Network Communications* **30**, 403–415 (Dec 2015).

[3] "Wireless backhaul evolution delivering next-generation connectivity," Technical report, ABI Research (February 2021).

[4] Lashgari, M., Tonini, F., Capacchione, M., Wosinska, L., Rigamonti, G., and Monti, P., "Fiber- vs. microwave-based 5G transport: a total cost of ownership analysis," in [*2022 European Conference on Optical Communication (ECOC)*], 1–4 (2022).

[5] Larsen, L. M. P., Checko, A., and Christiansen, H. L., "A survey of the functional splits proposed for 5G mobile crosshaul networks," *IEEE Communications Surveys & Tutorials* **21**(1), 146–172 (2019).

[6] O-RAN Open Fronthaul Interfaces Working Group 4, "Control, user and synchronization plane specification," technical specification (April 2022).

[7] O-RAN Open Xhaul Transport Working Group 9, "Xhaul transport requirements," technical specification (February 2021).

[8] Roblot, S., Hunukumbure, M., Varsier, N., Santiago, E., Bao, Y., Langouet, S., Hamon, M.-H., and Jeux, S., "Techno-economic analyses for vertical use cases in the 5G domain," (2019).

[9] Mesogiti, I., Lyberopoulos, G., Setaki, F., Di Giglio, A., Pelcelsi, A., Serra, L., Zou, J., Tzanakaki, A., Anastasopoulos, M., and Theodoropoulou, E., "Macroscopic and microscopic techno-economic analyses highlighting aspects of 5G transport network deployments," *Photonic Network Communications* **40**(3), 256–268 (2020).

[10] Lashgari, M., Tonini, F., Capacchione, M., Wosinska, L., Rigamonti, G., and Monti, P., "Techno-economics of fiber vs. microwave for mobile transport network deployments [invited]," (12 2022). Available at https://www.techrxiv.org/articles/preprint/Techno-economics_of_Fiber_vs_Microwave_for_Mobile_Transport_Network_Deployments_Invited_/21725186.

[11] O-RAN Open Xhaul Transport Working Group 9, "Xhaul packet switched architectures and solutions," technical specification (July 2022).