Fiber To The Room Challenges and Opportunities

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***Abstract*—Fiber to the Room (FTTR) represents the next stage in fiber optic diffusion, offering superior performance compared to traditional FTTx architectures. This pervasive fiber architecture extends high-speed, low-latency connectivity directly to users' premises. However, FTTR introduces novel challenges in network design and management, especially in the context of Multi-Access Edge Computing (MEC). This paper explores FTTR's characteristics including bandwidth, low latency, and data isolation, while highlighting its compatibility with next-generation service demands. We also discuss FTTR's alignment with the F5G service classes: Full-Fibre Connection (FFC), Enhanced Fixed Broadband (eFBB), and Guaranteed Reliable Experience (GRE). These insights emphasize FTTR's transformative potential and its pivotal role in shaping the future of fiber optic networks, particularly within the emerging MEC ecosystem, facilitating advanced digital services with unprecedented speed and efficiency.**

***Index Terms*—FTTR, PON, MEC, Optical Access Networks, DBA, FBA**

I. Introduction

Broadband communications are experiencing a great boost driven by new services such as online games, telemedicine, real-time interactive HD videos and online education. Actual challenges are arising by future-oriented service experiences such as augmented reality (AR), ultimate HD virtual reality (VR) and holographic interaction which represent nowadays the future ambitious targets [1].

Fixed networks play an essential role in that evolution. Thus, the ETSI created the Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G) initiative. ISG F5G aims to establish generational planning, and promote the expansion of the technology to as many sectors as possible via Fibre-To-The-Everywhere-and-Everything (FTTE). It represents a unique opportunity to frame the developments of other standards developing organizations (SDOs) in a forward-looking vision for the fixed networks in close collaboration with SDOs and relevant stakeholders in the industry [2]. ETSI ISG F5G has defined new ambitious use cases that require a fiber connection to the room as an extension of the fiber-to-the-home (FTTH), in order to meet the high requirements for the new demanding services. Fibre-to-the-room (FTTR) is a new kind of in-premises networking technology that is expected to provide high-bandwidth and reliable transmission. The FTTR opens new opportunities and perspectives that have been gathered also by the ITU-T SG15 Q3 that started the study of FTTR technology in 2020, with the aim of understanding the new use cases for FTTR and deriving the corresponding network requirements prior to developing specifications [3].

FTTR will enable a *fabric* of seamless wireless connections by either high-frequency radio technologies (e.g., at mmWaves and THz, which offer very large bandwidths for transmissions) or through free space optics (e.g., the Li-Fi, which offer very large bandwidths and reduced EM pollution) [4], [5]. Few works in the literature highlight the need of FTTR technology to enable Wi-Fi coverage avoiding the bottleneck created by the fixed networks within the home and overcoming the impact of APs interference [6], [7].

In this paper, we propose a FTTR architecture based on two cascaded Passive Optical Networks (PONs) to bring the FTTR connectivity within the user premise. We evaluate the benefits of FTTR in terms of end-to-end performance in the context of edge computing deployment. We show the advantages of FTTR deployment as an enabler for new high QoS services through a high level analysis of performance metrics like latency and jitter.

II. FTTR Network Architecture and Challenges

We consider the reference architecture as shown in Fig. 1 where a FTTR architecture is realized by means of a primary PON which spans from the Central Office (CO) to the customer premises. This first PON stage is generally organized in multiple 1:N splitting levels and can be utilized to reach both traditional Optical Network Terminations (ONTs) and customer infrastructures equipped with a secondary PON. The secondary PON, thanks to a single splitting level, distributes the optical fiber towards 2-8 ONTs spread for example across a campus area, an industrial plant, or a residential building.

The secondary and primary PONs are interconnected through a so-called *Residential GateWay* (RGW) which is deployed at the customer premises. The GW interacts with the primary PON through an ONT interface and acts in the secondary PON as OLT. As PONs are generally based on time or wavelength division multiplexing, the RGW shares the optical resources in the primary PON with other ONTs through multiple access mechanisms by interacting with the OLT at the CO. Instead, optical resources in the secondary PON are completely devoted to the devices in the secondary

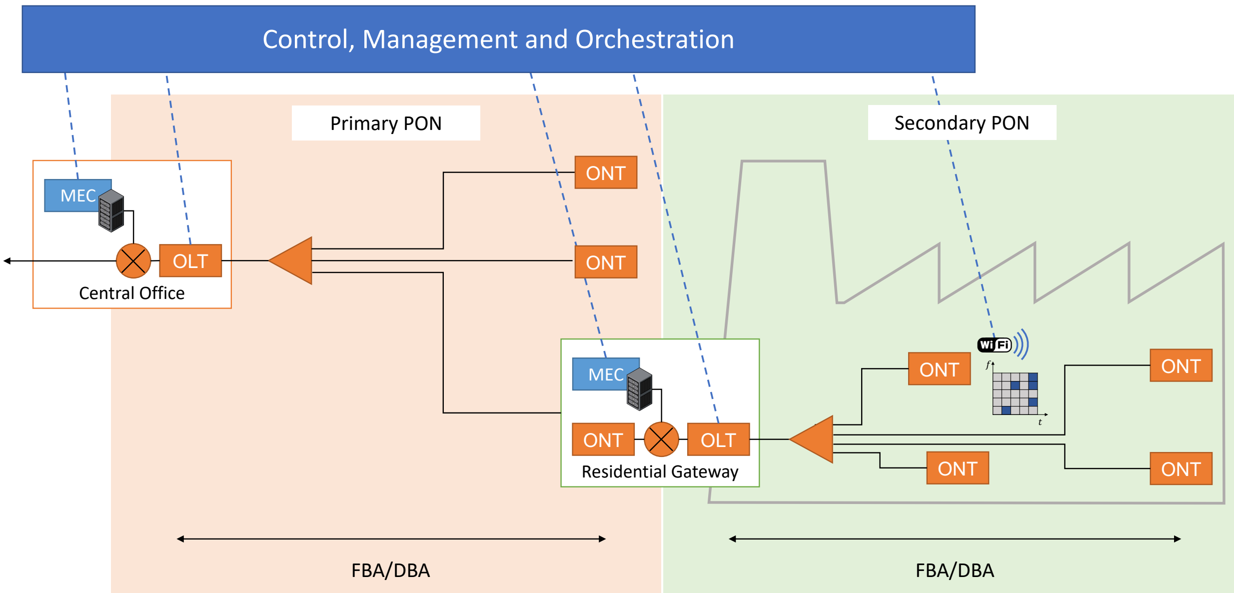

Fig. 1: FTTR architecture.

PON. In this segment, the RGW is responsible for resource allocation among ONTs in the FTTR.

Resource allocation mechanisms in PONs have been shown to significantly impact achievable performance in terms of bandwidth and latency. In request-grant transmission opportunities are provided to the ONTs by the OLT which performs Dynamic Bandwidth Allocation (DBA) operation. Such a mechanism allows efficient multiplexing among ONTs but introduces a handshaking delay which may not be compatible with low latency services. Alternatively, with a Fixed Bandwidth Allocation (FBA) mechanism resources are reserved for specific ONTs or services to transmit in a grant-free fashion. Such an approach guarantees a very low latency but comes at the cost of lower network efficiency.

With the combination of multiple PONs, FTTR poses the challenge to perform such resource allocation jointly for the primary and the secondary PON. Enhancement of performance can be achieved by synchronizing transmission opportunities in primary and secondary PONs [8] which in turn requires additional control at the RGW. Software Defined Networking appears also as a viable solution for the need of integration [9], thanks to the possibility to control OLTs at the CO and at the RGW via open standard protocols, e.g. NETCONF, at a unified control and management layer, able to map service requirements into ad-hoc resource allocation.

It is worth mentioning that a relevant technology for FTTR is represented by IEEE 802.11be, also known as Wi-Fi7 (and the upcoming Wi-Fi8), which offers the possibility to connect to the FTTR infrastructure to devices in mobility while at the same time offering bandwidth levels (up to 9.6 Gbps) which are in-line with current PON infrastructures. Analogously to recent mobile networking generations (4G, 5G), new generation Wi-Fi is based on Orthogonal Frequency-Division Multiple Access (OFDMA) and allows a fine grade control of resource allocation and latency compared to previous Wi-Fi generations.

Multi-Access Edge Computing (MEC) emerged as a promising paradigm to deploy microservices at the edge with low-latency and reduce traffic burden in transport networks. Central office (CO) architectures with MEC-enabled OLTs have been proposed for this purpose [10]. FTTR represents an interesting architecture as it enables MEC deployment at RGW[11]. In fact, industrial campus operators are expected to build and maintain their private MEC data centres, in which the computing resources and data are confined within their infrastructure campus to achieve higher data isolation. The possibility to deploy service instances at the RGW together with resource allocation control in the FTTR, allows to support extreme low-latency and high bandwidth demanding services.

Finally, the possibility to control resource allocation in primary and secondary PONs and in the Wi-Fi access together with the possibility to orchestrate MEC-based services at the CO or at the customer premise enables the deployment of end-to-end slices with differentiated resource allocation and orchestration based on targeted slice performance.

III. FTTR Performance and Enabled Services

Among the challenges posed by FTTR architecture, resource allocation and orchestration play a fundamental role as they determine performance levels achievable with FTTR architecture in terms of bandwidth and latency. Attainable performance, in turn, shape the set of novel services enabled by FTTR.

In Fig. 2 we show FTTR RTT latency for different bandwidth allocation strategies. Here, we assume both primary and secondary PONs being implemented through a TDM 10 Gbps capable XGS-PON without any coordination scheme between

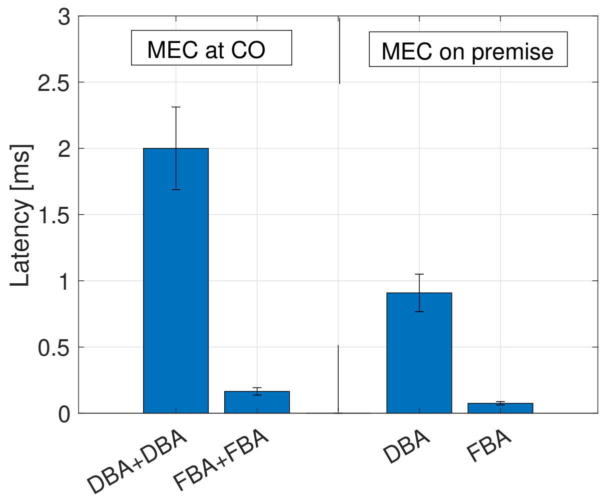

Fig. 2: FTTR performance with different MEC deployments.

the ONT and the OLT at the RGW that could improve the performance wrt the shown results. Data are derived from experimental measurements on commercial Calix E7-2 XGS-PON. In particular in the left side in Fig. 2, we compare the performance of DBA mechanisms applied at both the primary and secondary PONs (DBA+DBA) vs. the case where FBA is applied in both segments (FBA+FBA). The Calix *Strict Priority* algorithm is adopted as DBA algorithm. In such a scenario, packets generated at the FTTR ONTs have to traverse the entire FTTR architecture up to the OLT at the CO. Results show that the latency contribution of the two PON stages is 2.0 ms average with DBA+DBA and drops to $\sim$ 165 µs with FBA+FBA. After traversing the two PON stages, traffic can be terminated at a service instance deployed on a MEC at CO or traverse the data network.

Right side of Fig. 2 shows the latency achievable with FTTR when a service instance is deployed on a MEC on premise infrastructure, i.e. at the RGW . In this case latency decreases to 0.91 ms (DBA) and 75 µs (FBA) compared to the previous case since packets have to traverse only the secondary PON. It is worth mentioning that in this case the entire bandwidth of the secondary PON is available to the customer while in the MEC at the CO, optical access resources are shared among all the connected ONTs in the primary PON. Finally, it is worth noticing that both FBA and FBA+FBA configurations are characterized by very limited jitter compared to DBA+DBA and DBA. This makes FTTR a viable solution not only for bandwidth demanding and low latency services, but also for jitter-sensitive services such as extended reality and industrial automation.

The F5G initiative has introduced three distinct service classes that serve as the foundation for next-generation service offerings. *Full-Fibre Connection (FFC)* emphasizes the vision of end-to-end fiber connectivity, advocating for the deployment of fiber-optic infrastructure deep into residential and commercial premises. This class aims to provide users with uncompromising high-speed and low-latency connectivity. FTTR aligns seamlessly with FFC by extending fiber connections within user premises, making it well-suited for applications like IoT. *Enhanced Fixed Broadband (eFBB)* focuses on significantly enhancing fixed broadband connectivity. It seeks to provide users with improved broadband experiences, enabling a wider range of applications and services. FTTR's ability to offer high-bandwidth connections and low-latency performance aligns perfectly with eFBB. It contributes to the overall enhancement of fixed broadband experiences, accommodating services such as real-time interactive HD videos, telemedicine, and online education. *Guaranteed Reliable Experience (GRE)* places a premium on dependable and consistent connectivity. It targets services and applications that demand high reliability and quality of service (QoS). FTTR's capability to provide dedicated bandwidth, low latency, and low jitter positions it as an ideal choice for supporting GRE services. Applications such as critical e-health, telemedicine, and industrial automation greatly benefit from FTTR's performance characteristics.

As shown in Fig.3, much like how MEC plays a pivotal role in enabling the diverse spectrum of services envisioned in 5G, MEC in FTTR serves as the essential infrastructure that empowers a range of transformative services. MEC in 5G facilitates Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communication (URLLC), and Massive Machine Type Communication (mMTC). In a similar vein, MEC in FTTR amplifies the capabilities for GRE, FFC, and eFBB service classes. In Table I, we provide a compre-

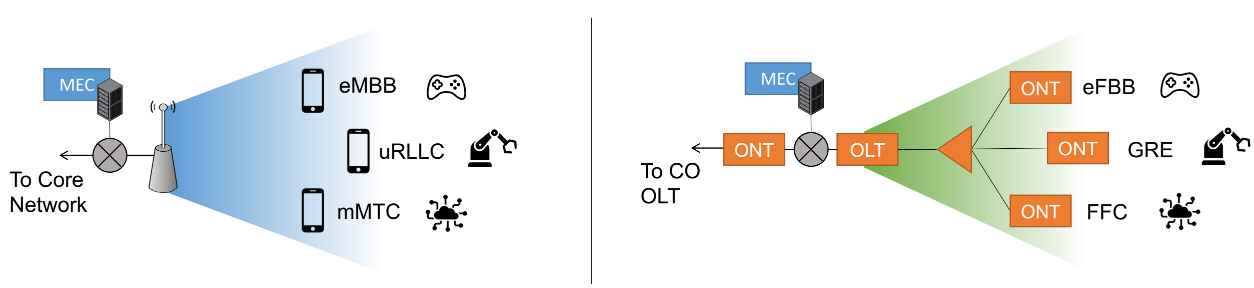

Fig. 3: MEC in 5G and FTTR .

	F5G Class	Extreme Edge	Low RTT	Data Isolation	High Bandwidth
Industrial automation	GRE	✓	✓	✓	
Extended Reality	eFBB	✓	✓		✓
Gaming	eFBB		✓		✓
Network Storage	FFC			✓	✓
Critical e-Health	GRE	✓	✓	✓	✓
IoT	FFC	✓		✓	

TABLE I: FTTR enabled services with F5G classification.

hensive mapping that underscores how FTTR characteristics seamlessly align with the demanding requirements of next-generation services. These characteristics encompass several key aspects:

Edge on Premise: FTTR's unique ability to extend fiber-optic connections deep into residential and commercial premises places it at the forefront of the "edge on premise" concept. By bringing high-speed, low-latency connectivity and the potential for MEC deployment directly to users' doorsteps, FTTR ensures that services can operate with minimal latency, resulting in a more responsive and efficient user experience. This is particularly critical for applications like IoT, where real-time data processing and decision-making at the edge are paramount.

Low Round Trip Time (RTT): The low-latency performance of FTTR is a critical enabler for a wide range of services. With FTTR, data can traverse the network swiftly, reducing the time it takes for information to traverse operators' network. Low RTT is essential for applications such as online gaming, where split-second reactions are vital, and telemedicine, where doctors and patients need real-time interactions for accurate diagnoses and treatment.

Data Isolation: FTTR's architecture allows for data isolation, ensuring that data traffic remains segregated and secure. This feature is particularly valuable for services that require stringent data privacy and security, such as network storage solutions. Users can confidently store sensitive information without concerns about data breaches or unauthorized access.

Dedicated Bandwidth: FTTR's provision of dedicated bandwidth ensures that users can enjoy consistent and reliable network performance without sharing optical resources with external users. This dedicated bandwidth remains consistently reliable even during peak usage periods. Services that demand high bandwidth, such as 4K video streaming, network storage, and augmented reality experiences, can operate smoothly without interruptions or degradation in quality.

In summary, the FTTR architecture not only meets but exceeds the expectations of next-generation services by offering a blend of low latency, dedicated bandwidth, data isolation, and edge connectivity. This strategic alignment empowers services across various F5G classes to deliver exceptional performance and reliability, ushering in a new era of digital experiences and capabilities.

IV. Conclusion

In this paper we presented an FTTR architecture and illustrated the challenges and opportunities of FTTR in terms of resource allocation, Wi-Fi integration, MEC deployment, and end-to-end slicing. FTTR targets very high bandwidth and low latency, overcoming bottleneck effects of traditional connectivity solutions. We provide some insights on achievable performance in terms of bandwidth, latency, and jitter and map such advantages on enabled novel services.

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References

[1] X. Wu, Y. Zeng, X. Si, X. Wang, and X. Liu, "Fiber-to-the-room (fttr): Standards and deployments," in *Optical Fiber Communication Conference*. Optica Publishing Group, 2023, pp. Tu3F–6.

[2] ETSI GR F5G 002 V1.1.1, "Fifth Generation Fixed Network (F5G); F5G Use Cases."

[3] ITU-T, "GSTP-FTTR "use cases and requirements of fibre-to-the-room (FTTR)"," technical Paper.

[4] J. Zhu, J. Li, N. Zhang, N. Wang, D. Zhang, H. Li, X. Duan, X. Wu, and L. Bai, "First field trial of fttr based on native management and control architecture for 5g small cell backhaul," in *Optical Fiber Communication Conference (OFC) 2023*. Optica Publishing Group, 2023, p. W2A.13. [Online]. Available: https://opg.optica.org/abstract.cfm?URI=OFC-2023-W2A.13

[5] I. Lau, S. Ekpo, M. Zafar, M. Ijaz, and A. Gibson, "Hybrid mmwave-li-fi 5g architecture for reconfigurable variable latency and data rate communications," *IEEE Access*, pp. 1–1, 2023.

[6] X. Liu, J. Li, X. Wu, J. Zhu, Y. Zeng, D. Liu, X. Wang, and D. Zhang, "Fiber-to- the-room (fttr) technologies for the 5th generation fixed network (f5g) and beyond," in *2022 IEEE Future Networks World Forum (FNWF)*, 2022, pp. 351–354.

[7] T. Chang, H. Xiong, F. Keshmiri, Z. Ren, and X. Wang, "Design of dual-polarized beamforming wifi antenna array for fttr applications," in *2022 International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, 2022, pp. 1–3.

[8] F. Effenberger and Y. Luo, "Pon for fiber to the room," in *Asia Communications and Photonics Conference*. Optical Society of America, 2021, pp. T3C–1.

[9] A. Marotta, D. Cassioli, K. Kondepu, C. Antonelli, and L. Valcarenghi, "Exploiting flexible functional split in converged software defined access networks," *Journal of Optical Communications and Networking*, vol. 11, no. 11, pp. 536–546, 2019.

[10] C. Centofanti *et al.*, "Improved DASH Video Streaming Performance by MEC-Enabled Optical Access," in *Asia Communications and Photonics Conference 2021*, 2021.

[11] A. Marotta *et al.*, "Performance Evaluation of MEC-enabled Fiber To The Room Architecture," in *IEEE International Conference on Advanced Networks and Telecommunications Systems*, 2023.