ETSI White Paper No. #41

The Fifth Generation Fixed Network (F5G): Bringing Fibre to Everywhere and Everything

1st edition – September 2020

ISBN No. 979-10-92620-36-5

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Executive Summary

Fibre networks are the foundation of the twin transitions (green and digital) of our society, providing sustainable and cost-efficient communication with high bandwidth, stability, reliability and reduced latency, enabling a sustainable economic growth through advanced services and applications for users, businesses, and industries.

The wireless industry created an efficient and successful ecosystem based on generations that gather the alignment of all stakeholders. In contrast, the wireline industry presents significant fragmentation that does not reap the benefits that large scale and aligned developments can bring to operators, developers, manufacturers, and users.

ISG F5G aims to create the foundations for a structured approach to the evolution of the fixed networks, establishing generational planning, and promoting the expansion of the technology to as many sectors as possible via Fibre-To-The-Everywhere-and-Everything (FTTE).

ISG F5G does not intend to duplicate the efforts already on-going in other SDOs but, instead, frame those developments in a forward-looking vision for the fixed networks in close cooperation with those SDOs and relevant stakeholders in the industry.

Moreover, ISG F5G considers other complementary technologies, as Wi-Fi 6 and other wireless technologies for the last metres, to enable the end-to-end vision that fulfils the several use cases already identified.

In this document we will elaborate on:

- The evolution of on-premise, fixed access, and aggregation networks, and how ISG F5G opens the opportunity for a closer coordination between these networks that can be regarded as a single extensive optical network.
- A general description of the main characteristics of ISG F5G, enabling use cases such as Cloud VR, Cloud Desktop, Cloud-enterprise, online gaming, online education, online medicine, Smart home, Smart factory, and Smart city, and the support for the evolution of 5G networks.
- The main features of ISG F5G as Enhanced Fixed Broadband (eFBB), Full-Fibre Connection (FFC) and Guaranteed Reliable Experience (GRE).
- The value of ISG F5G to all stakeholders and how it supports the evolution of economy and society and allows moving in the directions of network simplification, cost-efficient ODN buildout, end-to-end management, and the adaptation to the cloud age.
- Finally, ISG F5G is just the beginning and a first step for more generations to come.

The pandemic situation further highlights the importance of reliable and efficient broadband infrastructure that enables work-from-home, e-education, e-health, e-government, and many other services. It is vital to prepare our networks for the next step of evolution, so that they can deliver the capacities required for enhanced services and ensure a sustainable future.

ISG F5G creates a great opportunity for all interested stakeholders to come together in ETSI and define a common approach to the next generation of on-premise, access and aggregation in the fixed network domain.

1 Introduction

We are entering an exciting new era of communications, and fixed networks play an essential role in that evolution alongside and in cooperation with mobile networks. Fixed networks offer higher bandwidths and greater availability than mobile networks, despite the fact that they are less visible to the end users. These advantages will continue with the right development and investment in full fibre solutions using the latest technologies. Only by upgrading our fixed networks will we be ready to support the promising applications of the future, such as ultra-high definition video streaming, e-health, cloud office, online education, online entertainment, virtual reality (VR), and augmented reality (AR).

Next generation fixed networks are essential for complementing and supporting the 5G/Wi-Fi 6 wireless networks being deployed across the world, that would be hardly viable without F5G, as well as supporting the growing number of cloud services that require high bandwidth and/or low latency connections. Building on previous generations, F5G is being designed to bring unprecedented benefits to fixed networks and communications, similar to what 5G has brought to mobile.

The ETSI ISG F5G initiative creates a unique opportunity for the fixed network stakeholders (operators, suppliers and users) to understand the services needed, analyse the current status, and develop strategies and solutions. In doing so, the return on investment from fixed networks can be maximized by delivering enhanced quality of experience to users. In this White Paper, we present the vision, value, use cases, features, and technologies of F5G, aiming to foster a global effort to realize its full potential for our society in this new era.

2 Why F5G?

2.1 Why F5G is necessary

Fixed networks have gone through the narrowband era (64 Kbps per subscriber), wideband era (2 Mbit/s per subscriber), broadband era (20 Mbit/s per subscriber), and ultra-broadband era (100 Mbit/s per subscriber). Today, fixed networks are arriving at the 5th generation (1 G/bit per subscriber), the F5G.

From the progression of wireless systems over the past 20 years, it is clear that a restricted leading group of standards development organizations (SDOs) has created a well-regulated and well-timed plan of generations, from 3G, then 4G, and now 5G. The wireless industry has greatly benefited from this plan, in that all operators, vendors and other stakeholders became aligned, and as a result, wireless services became very successful. In contrast, the progression of fixed broadband access has been determined by the activities of numerous SDOs and Fora, and independent operator activities. This has resulted in somewhat fragmented fixed broadband technologies, with several important systems being delayed by many years due to conflicting movements in the industry, in part reducing the prospects for fixed access networks relative to their wireless counterparts.

Another key point is sustainability. Copper cable has maintained its value through several generations of networks, but has reached its performance limits. In order to make a new sustainable network for several generations, we need to move to fibre cable.

ISG F5G considers sustainability as a basic pillar in two senses. First in its economic sense, looking for designs that allow its future evolution through the use of pure fibre networks that guarantee useful lives of over 15 years. Second, in its green sense, seeking better energy efficiency and avoiding the use of materials with limited availability and higher carbon footprint such as copper.

ISG F5G aims at the definition of a set of fixed network technologies that together represent the fifth generation, developed in synergy with the above mentioned SDOs that have traditionally significantly contributed to the evolution of fixed access and transport. In the following evolution of fixed networks, planning of generations, in a similar approach to that adopted for mobile, can significantly improve the level of results obtained and benefit the market.

2.2 Fixed Network Evolution

2.2.1 The evolution of fixed Access Network

Fixed network consists of the customer premise network, access network and the aggregation network, which use different technologies and evolve at different paces. ISG F5G will produce closer coordination between these network layers in an integrated optical network.

Access technology evolution was driven by applications and services, so the network generations can be demarcated accordingly.

The first generation of fixed networks were telephone networks and services were mainly audio services. At the end of this period, data communication on dial-up access and integrated services digital network (ISDN) appeared, while email and simple Internet browsing applications were introduced.

With the global adoption of asymmetric digital subscriber line (ADSL) technology, the fixed network entered the second generation, which was the prelude of the broadband era and the high-speed development period of the fixed network. Web browsing, email, and search engines became important applications.

In 2008, the Federal Communications Commission (FCC) officially redefined the "broadband" as 25 Mbit/s or higher. In 2010, Europe announced the EU2020 and Digital Europe Plan, which defined the goal of 30 Mbit/s full coverage for the broadband network in Europe. The world had officially entered the third generation of fixed networks, that was called the NGA (Next Generation Access Networks) era.

In this era, internet protocol television (IPTV) became a powerful tool for carriers to improve market share and service differentiation. Operators adopted the "fibre deep" network architecture and introduce the new Very high-speed DSL (VDSL) technology on the twisted pair cable to achieve higher bandwidth. Optical fibre communication technology was applied to the Access Network for the first time to implement the fibre to the “x” (FTTx) network architecture, e.g. fibre to the curb (FTTC) and fibre to the building (FTTB). Based on these architectures, operators also introduced enhanced copper-based technologies like VDSL2 and VDSL vectoring to reuse the twisted pair wire on the last mile and provided access bandwidth up to 100 Mbit/s.

4K HD and fibre broadband signalled the arrival of the fourth generation of fixed networks. Fibre to the home (FTTH) deployments by the leading operators using gigabit passive optical network (GPON) technology provided good examples for global optical broadband development. Carrier-grade broadband networks were required to provide stable access capabilities of 100 Mbit/s or higher. The optical access network, with its advantages of high bandwidth, stability, simplified architecture, and long-term development, had become the most competitive network in the eyes of global operators. By 2014, the number of global FTTH users had reached 200 million.

Meanwhile, as a supplement to FTTH, twisted pair wire technology made another step forward. Super Vectoring and G.fast can provide access bandwidth up to 500 Mbit/s over the last few hundred meters of twisted pair wires.

2.2.2 The evolution of Aggregation Network

The evolution of Aggregation Network Technology ran in parallel with the fixed Access Network technology, which is driven not only by applications indirectly, but also by network restructuring, e.g. from a hierarchical network to a flat network, also driven by the evolution of mobile and cable networks.

The Aggregation Network evolved from Frequency Division Multiplex (FDM) in the very beginning to Plesiochronous Digital Hierarchy (PDH), introduced by ITU-T Recommendation G.702 in 1970s and designed to support digital voice channels running at 64kbps. Different countries/regions adopted PDH with different hierarchy schemes like T-1 and E-1. The maximum transmission speed supported by PDH was 564 Mbps and was used for many years.

With the common deployment of optical technologies, synchronous digital hierarchy (SDH) was standardized as ITU-T Recommendation G.707 in the 1990s to meet the interoperability and bandwidth requirements from telecom operators. Still SDH wasn't the only optical technologies. Synchronous Optical Network (SONET) was adopted by North America. The typical line speeds of SDN/SONET were 155M/622M/2.5G/10G at that time.

The first wavelength division multiplex (WDM) system was launched at 1992. There were up to 32λ supported in a single fibre. Fixed optical add drop multiplexer (FOADM) technology was later developed to add/drop optical signals.

The optical transport network (OTN) was designed as an international standard (ITU-T Recommendations G.709, G.872 and G.798) around 2000.However, it wasn't widely deployed at that time. On the contrary, SDH was reborn with the Multi-Service Transmission Platform (MSTP) which supports the transportation of Ethernet, Asynchronous Transfer Mode (ATM) and other data traffic types. The optical transmission speed was up to 40 Gbit/s. WDM could support up to 80λ and reconfigurable Add-Drop Multiplexers (ROADM) were introduced.

From 2010, 100Gbit/s line speed was commercially deployed. Multiservice OTN (MS-OTN) started to emerge. Meanwhile telecom operators started to abandon SDH/SONET networks.

Earlier on, there were no specific aggregation networking technologies being deployed, but the technologies used were the transport network technologies. Later, several operators have moved towards a specific aggregation network segment using different kinds of packet network technologies including IP, Carrier Ethernet and MPLS. The reason for going packet was the possibility to have easier multiplexing gains in the aggregation segment and operators were able to choose their aggregation capacity and therefore their service quality for subscribers more freely. Also the end-user services were packet based anyway, therefore such a packet based aggregation network was adopted to save some of the conversions required otherwise.

Over the years, several generations of different interface capacities have been deployed running over different types of optical communication channels. Different carrier specific functionalities for the aggregation networks have been developed, for example, the provider backbone bridges (IEEE 802.1ad and IEEE 802.1ah), link aggregation (IEEE 802.1ax) and operations features (IEEE 802.1ag/ITU-T Y.1731).

2.2.3 The evolution of Customer Premises Network

The concept of customer premises network (CPN) originated from the demand of access network and CPN, which are sharing an indoor copper wiring, since the appearance of broadband access technologies. Before mobile computing (2003) and smartphones (2007) being widely used, wireline technologies were used in CPN, such as HomePNA (HPNA) over phone line, MoCA over coaxial cable, IEEE P1901 over power line and ITU-T G.hn (for both phone line, coaxial cable and power line), which provided speeds from several Mbit/s to multiple Gbit/s (now).

Since 2007, the demand for wireless connection rapidly expanded from computers to smart terminals such as smartphones and tablets, and Wi-Fi technology quickly became the mainstream technology for CPN. Till now Wi-Fi has gone through six generations from Wi-Fi1 to Wi-Fi6, and new unlicensed spectrum was marked, including 2.41~2.48 GHz, 5.125-5.925 GHz. The corresponding capability of these technologies ranges from several megabits of Wi-Fi1 to a maximum of 10 Gbit/s of Wi-Fi 6, and support more and more applications.

The path to F5G will require not only changes in the access technologies but also in the aggregation network and customer premises network. The fact that this evolution will be based on a full optical communication end-to-end, opens new opportunities for increasing the synergies between access and aggregation networks.

3 F5G overview

3.1 F5G general description

The fifth generation fixed network is characterized by ultra-high bandwidth, integrated all-optical connections, and optimal service experience, which are reflected by newly introduced scenarios, services and applications.

For example, cloud-based virtual reality (VR) services have entered carriers' business horizons. Different from screen-based video services, VR services bring a completely new video experience with full-view and immersive charm. Leading carriers expect VR services to be the next-generation of IPTV services. The multi-gigabit network-based HD video communication, voice control, and smart home will become more and more popular.

The multi-gigabit access capability of the fifth generation fixed broadband network not only serves home users, but also extends to the entire industry including office, manufacturing, and other businesses, enabling the digital transformation of the entire society. Fibre broadband will be deployed in factories, mines, docks, and oilfields to implement industrial automation. Automation machinery and robots with precise control will replace manual labour, achieving efficient and automated unmanned factories.

Fibre broadband will be extended from large enterprises to small and medium enterprises and companies to provide them with various private line interconnections and cloud access. Fibre broadband will be available in many hotels, providing business travellers with anytime, anywhere office experience when traveling.

Furthermore, fibre broadband will be extended from dedicated education networks to offices, classrooms, laboratories, teachers' apartments, students' dormitories, and even desks, and from colleges and universities to secondary schools, primary schools, and professional education institutions, and will provide teachers and students with various teaching/learning methods, such as cloud-based education, online learning, offline learning, cloud-based textbooks, cloud-based notes, and multimedia teaching, to implement book-free and schoolbag-free education. Compared with the fourth-generation's 100 Mbit/s fibre broadband, the fifth generation fibre broadband will provide 10 times more bandwidth, 10 times more connection from home to things, and ultra-broadband application experience featuring high reliability and near zero waiting time, fully realizing the digital transformation of the entire industry.

3.2 F5G Use Cases

The deployment of the first FTTH generations enables other applications by developing the full fibre network. The maturity of optical access technologies for mass FTTH deployment is paving the way for a larger fibre market size. The use cases serve as an input for formulating network requirements and choosing the building technologies of the F5G network.

- Existing Scenarios Enhancement

F5G enhances current optical networking scenarios including mobile xHauls and optical local area network (LAN) connectivity. Typically, the Optical Line Terminal (OLT) shelf can enable FTTAntenna by using dedicated Point to Point (PTP) or PON cards. The passive and active parts of fibre access networks are the companion of mobile networks for backhaul and fronthaul. Moreover, the maturity of passive and active optical access solutions based on 10 gigabit symmetrical PON (XG(S)-PON) enables deployment of LAN campus solutions with much higher bandwidth and more connections. Passive Optical LAN (POL) based on such PON technologies will provide fibre deeper and deeper into the customers' household devices and will also serve next generation high bit-rate wireless links for which air propagation could be a limitation. This first approach for campus or hospital with POL, will certainly offer initiatives for FTTRoom in the coming decade.

- Operational Excellence

Efficient operation for excellent customer experience is enabled by F5G. The use cases include digital management of the Optical Distribution Network (ODN) for cost efficient optical fibre deployment and maintenance, securing the network access more strongly for higher reliable services, and enabling advanced monitoring and intelligent telemetry.

In addition to the organic growth of the current use cases, emerging innovative use cases with various applications are to be enabled by F5G as well. These use cases will be differentiated across a wide range of scenarios (i.e., on premises, enterprise, all types of vertical industries). There are already many use cases identified, including but not limited to the following:

- Cloud VR

Based on cloud computing and rendering technologies, Cloud Virtual Reality (VR) applications introduce a large amount of information interaction between the terminal and the cloud server. It will place extremely high requirements on the bearer network (e.g. bandwidth, latency and packet loss), requiring upgrade to bearer network technology and architecture. The existing bearer network will be able to support a very early stage of Cloud VR (e.g. 4K VR) with quite a limited user experience, but it can't meet the requirements for massive development of Cloud VR with full experience. To support more applications and ensure high-quality experience, much higher bandwidth (e.g. > 1 Gbit/s) and lower latency (e.g. < 10 ms) are necessary.

- Cloud Desktop

Cloud desktop is a virtual personal computer (PC) host connected to the cloud through the client, which can realize the user's office environment anytime and anywhere, and can maintain an operation experience completely consistent with that of a PC, satisfying requirements of HD screen, smoothness and low latency. The cloud desktop application not only reduces the burden of carrying laptops during business travel, but also ensures the security of enterprise information.

- Cloud Enterprise

At present, the digitalization of enterprises continues to accelerate, and the cloud demands for daily office, enterprise resource planning (ERP), consumer relationship management (CRM) and other core businesses are increasing. Because of the differences in business deployment on the cloud, there are significant differences in the demands of enterprises for cloud dedicated lines. For small and micro-enterprises, the main demand is high cost-effective and agile dedicated line connection. Large and medium-sized enterprises need high reliable, elastic, and wide bandwidth specific line connection.

- Online Gaming

Online games are a popular mode of entertainment and social contact. Online games are characterized by strong interaction, high immersion, and full interest. For players to get a better e-competition experience, the response delay is very important. Too much delay in transmission will affect the synchronization state of servers and players. This will affect the user experience. The current network may be able to support the early stage of online games with limited user experience, but it can't meet the requirements for massive development of online games with full user experience. Therefore, in the commercial application of gaming, smooth, high bandwidth access service is essential.

- Online Education

Online education can realize learning at any time and place. Different from the traditional teaching mode, online education can transfer knowledge outside the classroom. Online education, as a flexible, reliable, and sustainable education method, has attracted more and more attention. It can be applied to higher education, primary and secondary education and vocational education. An online classroom system is coupled to teacher-side and student-side equipment. Platform providers, curriculum content producers, network providers, terminal providers and other industrial partners jointly build a real-time online interaction system, supporting voice, image and video among multiple users, thereby realizing teaching, practice, testing and evaluation online.

- E-health

E-health involves computer technology, remote sensing, telemetry, remote control technology. The objective is to provide access to all the advantages of medical technology and medical equipment of large hospitals or specialized medical centres to patients in poor conditions or remote areas. At present, telemedicine technology has led to the integrated transmission of digital, image and voice, the realization of real-time voice and high-definition image communication, and the application of remote operation. Ensuring the accuracy and reliability of the treatment process is a critical part of the e-health development, and thus places special requirements on the network.

- Smart Home

Smart home is the combination of 4K / 8K high-definition video entertainment, intelligent control of home equipment and information exchange. It involves the Internet of things, cloud computing and other technologies. At present, the connection between smart home devices is mainly through Wi Fi, ZigBee®, and Bluetooth®. It involves the support of many data sources in the home network with the required performance for each of them, and the bandwidth and stability of the external network connection must be high.

- Smart Factory

Smart factory includes the interconnection and system integration among the intelligent equipment, the intelligent control system, and the industrial Internet. Among them, the industrial Internet, which realizes the data collection of equipment and the networking of equipment, is the important foundation. Passive optical network technology, which uses optical fibre as transmission medium, has excellent immunity to electromagnetic interference, and also has the characteristics of passive and flexible networking, so it becomes the first choice technology for smart factories, particularly those with harsh environments.

- Smart City

The video surveillance system is the one of the important parts of a smart city. It requires a clear and smooth picture, stable transmission quality and fast deployment cycle, which places requirements on the network. With the evolution of video monitoring to ultra-high definition and intelligent video monitoring, the access network must be upgraded continuously. With the deployment of cloud and edge computing, the network infrastructure is required to support more artificial intelligence based auxiliary monitoring applications, while ensuring that the camera can continuously collect video 7*24 hours.

4 Main features and technologies of F5G

4.1 F5G main features overview

The characteristics that enable F5G to satisfy the demand for high bandwidth, massive connection and high quality of experience, can be represented in a three-dimensional space where to each dimension we associate one of the following feature groups: enhanced Fixed Broadband (eFBB), Full Fibre Connection (FFC) and Guaranteed Reliable Experience (GRE).

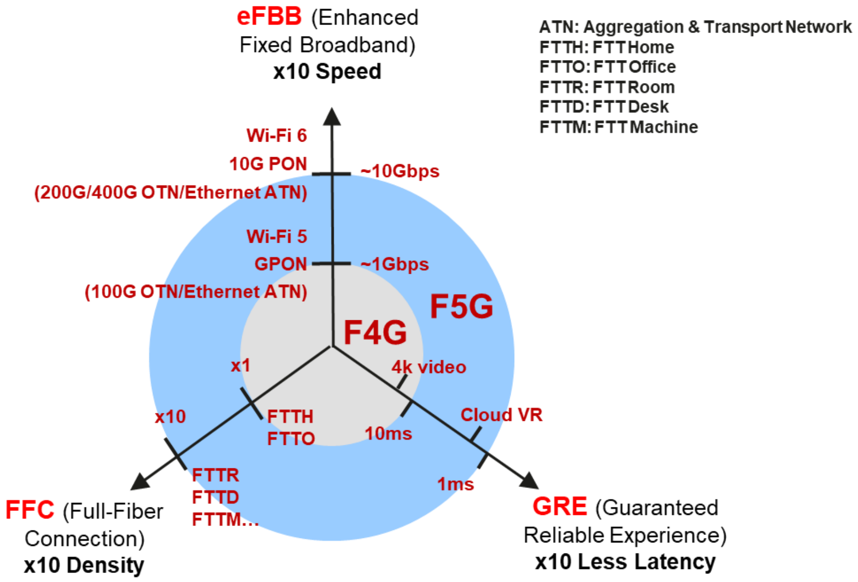

Figure 1: Features of F5G

4.2 Enhanced Fixed BroadBand (eFBB)

Enhanced Fixed Broadband (eFBB) is a feature group of F5G allowing the support of the demand of high bandwidth for the fixed network, larger than 1Gbps symmetric access bandwidth per user.

For residential customers, the coming decade will certainly propose a single network segment block based on the bonding of the FTTH and the Home LAN. From customers' perspective, the proof of an augmented connectivity by an optical technology relies also on their wireless experiences (e.g. Wi-Fi). Improvement of in-house connectivity quality from standard Wi-Fi to smart Wi-Fi is a must to enable an enhanced customer experience for XG(S)-PON.

For business customers, relevant technologies include the aforementioned POL and 5G cloud radio access network (C-RAN), which consists of front-haul, mid-haul and back-haul connections. When used for C-RAN, PON enables the sharing of the same optical distribution network (ODN) for multiple remote antennas and achieves the statistical multiplexing gain via a point-to-multipoint (PTMP) architecture, thus reducing the overall network cost.

XG(S)-PON fibre access technology will be widely deployed. The network has symmetric gigabit upstream and downstream bandwidth capability. The Wi-Fi 6 technology is used to break the bottleneck of the last tens of meters of gigabit connections.

F5G further increases the bandwidth by more than 10 times with respect to the current generation of broadband access.

The bandwidth of aggregation networks will be continuously upgraded. For example, the WDM wavelengths can be extended from C-band to L-band with 200 Gbit/s to 400 Gbit/s per wavelength OTN, which provides more than 40 Tbit/s capacity over each fibre. WDM will be extended from the backbone to the metro to connect the Access Network aggregator (OLT) and form an E2E all-optical network. This will support a converged network which enables end-to-end gigabit bandwidth capabilities.

4.3 Full-Fibre Connection (FFC)

The second feature group of F5G is Full-Fibre Connection (FFC), which is used to provide massive connections for extending the number of scenarios and fibre connected devices.

F5G extends fibre connection from Fibre-To-The-Home to a much broader application space including business and vertical users to provide ubiquitous connections. Hence the number of connections is increased by more than 10 times, enabling full-fibre connectivity.

In the home access domain, F5G further extends traditional FTTH to deploy fibre into each room (FTTR), and to provide complete fibre infrastructure for smart home and family life. Thank this new approach and to the Wi-Fi 6 deployment described before, the home environment can be covered with gigabit broadband access without blackspots (also defined as not spots). In the private line domain, by introducing small granularity (2Mbit/s) of traffic containers, the OTN will provide large number of flexible pipes with lower connection latency for business users. This guides the migration direction of MSTP services and resolves the quality of service issues of traditional Ethernet, VPN, and SD-WAN private line services. The OTN technology can further be associated with PON to implement wide coverage of OTN private lines through point-to-multipoint fibre access , providing high-quality private line services for SMEs and SOHOs with low cost and fast provisioning.

Optical fibres are the optimal connection medium for 5G base stations. 5G networks require large bandwidth, wide coverage, and low latency, which can be maximized only through optical fibre access and transport. Full-scale 5G deployment will increase the number of base stations by dozens of times. The deployment scenarios will become more complex and closer to end users. The distribution of 5G base stations will overlap with the ODN distribution of FTTH. Therefore, it is efficient to share the FTTH ODN to carry 5G services. The deployment of macro, micro, and femto/pico cell sites may require OTN and PON technologies for fronthaul or backhaul.

In the enterprise access domain, F5G can replace or augment the traditional Ethernet network with PON. Implementing LAN with PON can save the cost of cable and maintenance, because ODN has lower costs of deployment and maintenance compared with a traditional Ethernet network of switches and CAT6 cables.

With F5G, fibre access further penetrates into the production systems of industrial enterprises, connecting machines (FTTMachine) and industrial robots. Based on the high bandwidth, high reliability, low latency, interference-immunity, and high security features of fibre networks, TSNs (Time Sensitive Networking) can be implemented in support of the industrial digital transformation.

For industrial and security video applications, optical fibres can be connected to each smart camera to provide high-bandwidth and low-latency transmission channels, implementing high-speed connection to data centres supporting machine vision and facilitating the use of AI technologies in this field.

Massive connections need an infrastructure with a lot of fibres. The passive infrastructure cost (material + manpower) represents a large portion of the overall FTTH cost. It is essential to dimension the optical cables to make them capable of sharing multiple services: FTTH PON for residential customers, B2B services, and mobile x-haul. In addition, both PON and Point-to-Point optical solutions are possible candidates for each service depending on its bitrate and SLA (level of bitrate guaranteed, time to repair).

Full fibre connection calls for quick and cost-effective ODN deployment with high quality, reliable connections:

- Where possible, the existing infrastructures should be reused. If new civil engineering work is needed, the appropriate construction methods are to be used. Solutions as micro- or nano-trenching associated with micro-ducts and micro-cables can help to minimize cost and time by making construction work as fast and low impact as possible, avoiding major disruption to customers or the local area. They are more and more encouraged by municipalities and should allow FTTH rollout even in rural areas.

- To minimize the staff costs (which is one of the biggest cost for deployment), novel devices and solutions such as pre-connected/terminated cable solutions may be used to eliminate on site splicing and fusing, hence improve efficiency and cut costs.

- Customer connection is one of the bottlenecks for FTTH and POL (passive optical LAN) deployments. Solutions have been developed for indoor optical cabling: pushable low friction cables and pulling ropes for conduit use, discrete solutions for visible cabling. Optimizing solutions for single houses connection are now the key.

Normal fibre cable doesn't provide power supply. In case a local power supply is unavailable, hybrid power and fibre cables and connectors may be used to provide both remote powering and data connection for the terminal equipment.

The infrastructure deployed needs to be future proof to support PON system upgrades and will enable also Radio Access Network deployments for macro, micro and small cells.

4.3 Guaranteed Reliable Experience (GRE)

Providing Guaranteed Reliable Experience (GRE) is the third feature of F5G increasing customer experience.

High quality of experience needs to be guaranteed for the new applications enabled by F5G. Optical fibre technologies are the only means to support and guarantee high quality data transportation, minimum packet loss, and latency in the order of microseconds. Wi-Fi will be optimized to reduce the air interface latency, improve the reliability and interaction experience. The technical progress on Big Data and AI will be introduced into network domain to improve the automatic management and operation of E2E network and applications. Various kinds of applications are handled differently in the network to serve the quality of experience requirements.

High definition video, virtual reality, gaming, video communication, home security are high value residential services. Some of them, such as HD video, VR and gaming are highly bandwidth consuming and latency and packet loss sensitive. Milli- and even micro- second level latency transportation on OTN, PON and Wi-Fi channels is essential to these services. Intelligent identification of these services in real time in the network is also needed to allocate optimized network resources according to the change of user behaviour and service traffic.

B2B services of the telecommunication operator, e.g. those to vertical industries require different network performance. What they need are not only the high bandwidth, millisecond level latency, and high reliability, but also that they are assured over time. The network needs to be both flexible, allowing an easy configuration as required by the service, and rigid, to maintain for the needed time that configuration, to commit SLA to the business users, based on high precision clocking

The continuous optimization of both hardware and software technologies is needed to support guaranteed-quality F5G applications, including:

- **Programmability**. Software defined networking (SDN) and network function virtualization (NFV) are the basic technologies to enable software and hardware separation and programmable networking. SDN decouples the control plane and the user plane of the switching elements of the network, while the ETSI NFV framework provides a standard architecture for network function virtualization that enables more flexibility and quick response to scale in/out or move/deploy network functions whenever and wherever needed.
- **Autonomy.** Manual operation is not suitable for massive connections. Network management and operation autonomy is essential in order to provide a reliable and fast-deployed F5G network service. TM Forum is in the process of defining the Business Architecture (BA) [3] and the Technical Architecture (TA) for the Autonomous Network. An Autonomous Network can sense the real-time environmental changes, learn and make intelligent analysis, and provide advice to network operators or customers on making decision on optimization and adjustment. By applying closed-loop control and intent driven configuration in each autonomous domain, F5G will have the capabilities of "Self-X" functions (e.g., self–serving, self-fulfilling and self-assuring), and therefore will be able to provide a wide variety of services with "Zero-X" (e.g., zero-wait, zero-touch and zero-trouble) experience to both network operators and customers. The autonomy shall be applied to E2E management, maintenance, and service provisioning in order to enable fast rollout.
- **Low Latency.** E2E millisecond level latency is a challenge to the industry. To meet this, PON needs to be optimized to support micro-second level latency. The latency on the air interface of Wi-Fi has to be reduced to 1 ms or less to support high performance cloud services. For some high-value services, such as high-quality private lines, small-granularity OTN channels can be directly applied to achieve even lower latency.
- **E2E Slicing.** The multiple service fixed network supports differentiated quality of experience assurance with single physical network. Slicing technology is therefore an important feature. Multiple RF carrier slicing is needed on Wi-Fi air interfaces. User and service granularity slicing is needed on PON interfaces. Ethernet/IP and OTN network slicing are also needed to setup and operate E2E logical networks with different SLAs, managing them through the different network segments, with E2E automatic scheduling of all corresponding network resources.
- **Artificial Intelligence.** Artificial intelligence is a very powerful tool for service assurance both for O&M and also for the data plane. Embedded intelligent capabilities are needed for an automated multi-service network. Different kinds of applications need to be distinguished automatically, without touching the inner content to protect the user privacy. AI, by means of Big Data Analytics and Telemetry, allows the monitoring of the status of the network and that of its resources and their management in real time, readjusting policies and reconfiguring/reallocating resources in real time. Network failures need to be prevented by early prediction, and when that is not possible, they have to be diagnosed, isolated and fixed in the shortest possible time.
- **Interoperability**. The key of success for a faster deployment lays on the interoperability between different suppliers/vendors, meaning standard interfaces and open APIs, together with the

availability of reference models. The success of F5G adoption depends also on the integration and/or migration from legacy networks in the smoothest possible way.

5 Value of F5G

Fibre speed and user experience

F5G provides ultra-high-speed broadband services with full fibre networks. Fibre gives users the access to the highest communication speeds and the entire community new opportunities to grow economically. With greater accessibility and faster speeds households can connect to all of their devices without degrading performance, with more and better residential services, entrepreneurs have the infrastructure they need to innovate and city administrations have additional capacity to address local problems, from growing street traffic congestion to managing large databases. All this translates into improved economic performance for the whole society, with the creation of more jobs, more innovation, as well as the incentive for additional infrastructure investments and companies relocating or expanding in broadband-enabled cities.

F5G empowering our gigabit communities

The availability of full fibre networks can help in the building of 'gigabit communities', empowered by better communication resources they can use. Some studies suggest that gigabit broadband communities exhibit a per capita GDP approximately 1.1 percent higher than the similar communities with little to no availability of gigabit services. Full fibre networks are faster, more reliable, more sustainable, and provide great economic value to communities, making users more productive. More online services are accessible to the members of these communities thank to higher speed and capacity. Beyond high speeds and capacity, fibre is also more reliable, requiring fewer modem reboots and calls to the service centre than other technologies. So, fibre infrastructure becomes a catalyst for economic, educational, work, entertainment and governmental innovation and growth, and the investment in fibre creates value for all related players and improves the economic performance of a community as well as its quality of life.

The economic impact of F5G

In our digitally connected world, consumers increasingly require full-fibre, ultra-high bandwidth broadband network in their homes, whether for leisure, work, education or keeping in contact with friends and family. This means that when they need to move, particularly in the countryside, the presence and speed of internet connectivity is one of the factors that they consider when buying a house. Rolling out fibre across the country, not just within major cities, is delivering benefits in four main areas:

- F5G encouraging migration and digital transformation

F5G is the foundation of the new digital age and is a prerequisite for the digital transformation of the whole society. The F5G communication facilities are required for dealing with the ongoing increase of bandwidth used and with the introduction of new network characteristics for specialized applications or specific application behaviours.

F5G is supporting the recovery from the pandemic through facilitating remote work, location-independent learning and entertainment at home. Assuming that the pandemic will stay for some more time, it is important for the economy to have a well-connected society in which work can be more and more performed remotely.

Moving towards more optical communication and with it reducing the copper and electrical footprint of the communication networks has a positive effect to lower the carbon-dioxide emissions related to communication networks.

High speed connectivity encourages those that want to move out from cities by providing them with the ability to work from home, and access the same entertainment and other services accessible in urban areas. Often these incomers are families, helping to safeguard the future of local schools, while at the same time stimulating the local economy with new investment.

- F5G revitalizing communities

As well as bringing in new people, superfast broadband encourages existing residents to stay. It also provides the ability for local businesses to expand, invest and seek new opportunities. Just one example, in Cornwall, south west England, 58% of local businesses said that they were growing thanks to the connectivity fibre broadband had delivered. All of this leads to increased investment in the rural areas, providing residents with more choice and stimulating growth.

- F5G opening up new opportunities and markets

Fibre to the home is proven to increase customer satisfaction for existing services, and enables operators to offer new ones, such as video on demand, 4K/8K TV and smart home connectivity, Cloud VR. Deploying FTTH and even FTTR in rural areas opens up new markets for operators, enabling them to reach more consumers and increase revenues.

The economic benefits of FTTH, FTTR, FTTD, FTTM, for residents, businesses and the wider community are potentially enormous. While there are upfront costs in FTTH deployments, particularly around the last drop, equipment and methodologies are evolving to reduce these significantly. Now is therefore the time for operators to look at extending their FTTH networks and creating new revenue streams for the future, while encouraging growth.

F5G is enabling new applications through enhanced network characteristics and with that enabling new digital businesses. Specifically, F5G is allowing for new mission critical applications today through the low-delay and high reliability features.

F5G is simplifying the network still allowing for various deployment options, which will reduce the energy cost through optimizing the number of electric to optical and vice-versa conversions and through more passive elements in the network. It also reduces the number of human errors and equipment failures for a more robust operation of the network.

The integration of optical with wireless technologies at the very edge enables dense and high-speed wireless deployment. With the trend towards and necessity for shorter range wireless communication, the buildout for high-speed backhauling using optical networking technologies will be required in homes and enterprises campuses. With the F5G technologies the campus deployment will be more efficient and allowing businesses to enable the journey towards the cloud.

F5G is increasing the user experience in home and enterprises and with that increasing the service quality through more deterministic performance and optimizing the operational effort.

- F5G for future-proof infrastructure

The world of work is changing rapidly and becoming increasingly digital. More and more of us are knowledge workers, relying on fast connections to information stored in the cloud to do our jobs.

F5Gs will leverage cloud technologies for the control and management functionality which makes the technology more future proof and enables the integration of AI/ML technologies, and modernizes the way of end-users connecting, changing, or measuring connectivity and the services offered through the cloud. For enterprises, F5G will enable easier connection to any cloud-based software stacks internal or external to the enterprise.

Where we are based is less relevant, given the rise of video and audio conferencing. Therefore, installing superfast fibre broadband now is an investment in equipping communities with the infrastructure they need to not just survive, but to thrive in the future. Those areas that gain first mover advantage with fibre could well outstrip their neighbours. For example, one area has cemented its position as a centre for healthcare through a municipal fibre deployment, while it reports 100% occupancy of its business parks. By contrast, the neighbouring area without fibre deployment declared itself bankrupt during the economic downturn.

ISG F5G will standardize on a system level, which makes the interworking for the various components smoother and guarantees a sustainable migration path towards new generations of fixed networking. Also integrating the various technologies developed by other SDOs, will create a big picture, which makes the technology and its interrelationship better consumable and understandable for end users such as consumers and enterprises.

6 Evolution of F5G

F5G is expected to realize Fibre-To-The-Everywhere-and-Everything (FTTE see [2], and provides key performance metrics such as 1 Gbps experienced rate with guaranteed latency and reliability. Going forward, we expect F5G to continue evolving in order to support a ubiquitous intelligent society.

New application scenarios to be supported may include holographic communication, digital avatar life, full sensory (including tactile and haptic) internet. The widely deployed fibre infrastructure in F5G will not only serve as a communication network but also as a sensor network or many more applications.

The evolution of F5G, together with that of mobile 5G to 6G [1], will form a deeply synergized global network that supports ubiquitous connections and unprecedentedly diverse applications in the 5G era and beyond.

References

[1] 6G WIRELESS NETWORKS Vision, Requirements, Architecture, and Key Technologies, by Zhengquan Zhang, Yue Xiao, Zheng Ma, Ming Xiao, Zhiguo Ding, Xianfu Lei, George K. Karagiannidis, and Pingzhi Fan, IEEE VEHICULAR TECHNOLOGY MAGAZINE | SEPTEMBER 2019

[2} Strategic Research and Innovation Agenda 2021-27, "Smart Networks in the context of NGI", by European Technology Platform NetWorld2020, March 2020

[3] TM Forum IG1218 Autonomous Networks – Business requirements & architecture, July 8th, 2020

Glossary

ADSL	Asymmetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
CPN	Customer Premises Network
eFBB	Enhanced Fixed Broadband
F5G	Fixed Fifth Generation
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FOADM	Fixed Optical ADM
FTTB	Fibre To The Building
FTTC	Fibre To The Curb
FTTD	Fibre To The Desk
FTTdp	Fibre To The distribution point
FTTH	Fibre To The Home
FTTLA	Fibre To The Last Amplifier/Active
FTTM	Fibre To The Machine
FTTO	Fibre To The Office
FTTR	Fibre To The Room
FTTx	Fibre To The x
FFC	Full-Fibre Connection
GRE	Guaranteed Reliable Experience
GPON	Gigabit Passive Optical Network
IPTV	Internet Protocol Television
ISDN	Integrated Services Digital Network
IP	Internet Protocol
LAN	Local Area Network
MoCA	Multimedia over Coax Alliance
MSTP	Multiservice Transport Platform
MU-MIMO	Multi-User MIMO

NFV	Network Functions Virtualization
NGA	Next-Generation Access Network
NG-PON	Next-Generation PON
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONT	Optical Network Terminal
ONU	Optical Network Unit
OTN	Optical Transport Network
PDH	Plesiochronous Digital Hierarchy
POL	Passive Optical LAN
ROADM	Reconfigurable Add-Drop Multiplexers
SDH	Synchronous Digital Hierarchy
SDO	Standard Development Organizations
SONET	Synchronous Optical Networking
VDSL	Very high-speed Digital Subscriber Line
VR	Virtual Reality
XG-PON	10-Gigabit-capable PON (also known as asymmetric 10G-PON)
XGS-PON	10-Gigabit-capable Symmetric PON (also known as symmetric 10G-PON)
WDM	Wavelength Division Multiplexing
Wi-Fi	Wireless Fidelity (Wi-Fi)

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