Chapter

# Convergence of Wireless and Optical Network in Future Communication Network

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## Abstract

The requirement of data increases many-fold in recent years to support the newest technologies in B5G and 6G. Wireless is the last mile solution as access with an optical network as the backbone in future communication systems. Over the years in every new generation, the distance between the base station and the user is decreasing and the optical node is coming closer to the user. There are several technologies like AR/VR, AI, holographic communication, holographic telepresence, etc. are the main candidates in B5G and 6G, which are required high-speed connection with low latency. To support these services, it is almost mandatory that transmit data across the network should be smooth and seamless to provide successful communication. Providing a successful and appropriate wireless link among the users simultaneously to achieve the requirements is becoming more complex, hence challenging. The optical backbone of all wireless access networks requires supporting these user's requirements, needs to evolve continuously with wireless network evolution. This chapter will study the evolution of both networks to understand their cooperation, alignment, and support.

**Keywords:** Wireless network, 5G, Heterogeneous network, Massive MIMO, 6G, Cognitive radio, Optical network, Cognitive optical network, Ethernet PON

## 1. Introduction

Over the year, the number of connected devices (wirelessly and wired) is ever-increasing, will reach 13 billion by 2023 [1]. To support these always-connected devices, the demand for high speed, high reliability, low-latency, low-cost, dense connectivity, different types of mobility needs, and heterogeneous connectivity is escalating, which forced the telecommunications industry to enter into a new era of the future communication network (FCN) [2]. Furthermore, to unleash the full potential of Industry 4.0, guaranteed real-time communication between humans, robots, factory logistics, and products is a fundamental requirement [3]. The FCN incorporates 5G and beyond 5G network, whose main objectives will be application/service-oriented, which are on-demand and highly heterogeneous in nature [4]. To support ever-increasing devices for application-specific on-demand services, there is a strong requirement to view, design, and optimize the network from an end-to-end perspective.

To supports ever-increasing demand on requirements for different types of usage, applications, services, several technologies have been developed over the year. **Table 1** describes the important milestones in both wireline and wireless communication. The development of wireline communication first started in copper and later shifted to the optical domain. In the present day, optical fiber is used in the backhaul network and copper wire is used normally in the access network. In the case of wireless communication, communication first started in the sub-GHz range and slowly it moves towards high-frequency ranges. In the latest, wireless communication is moving towards the 60–100 GHz range (mmWave communication) [4, 5].

To facilitate 5G capabilities (latency less than 1 ms, more than 5 Gbps data rate for high mobile user, other quality of (QoS) and quality of experience (QoE), enhanced spectral, energy and network efficiency, smart security, etc.) FCNs need to enhance existing services. To fulfill 5G and beyond 5G stringent service requirements, it is essential to have an understanding of all available resources across networks (wireless and optical), across radio-access technologies (RAT) (various frequency domain), across services (different class of services and traffic type), across emerging and disruptive technologies (internet-of-things (IoT), artificial intelligence (AI), augmented reality/virtual reality (AR/VR)), and across cloud

| **Wireline Communication** | | **Wireless Communication** | |
|---|---|---|---|
| **Year** | **Milestones** | **Year** | **Milestones** |
| 1876 | A. G. Bell transmits the first sentence | 1894 | Transmission through radio demonstrated by J. C. Bose |
| 1877 | First long-distance telephone line | 1986 | Marconi demonstrates wireless telegraphy |
| 1927 | The first transatlantic phone call, from the US to the UK | 1901 | Send the signal wirelessly across the Atlantic |
| 1948 | Shannon published Shannon's formula | 1914 | first voice communication was established over a radio |
| 1956 | Kapany invented the glass-coated glass rod, named Fiber | 1946 | The first public mobile telephone was introduced by AT&T |
| 1958 | LASER invented by Schawlow and Townes | 1973 | Motorola makes a mobile call from a handheld mobile phone |
| 1960 | Kao demonstrate communication through fiber | 1992 | GSM starts its operation |
| 1970 | Corning Glass produced a practical fiber | 1997 | IEEE releases WiFi standard |
| 1973 | TCP/IP protocol proposed by Kahn and Cerf | 2003 | Birth of WWWW |
| 1977 | the first live telephone traffic through fiber optics | 2009 | Birth of the Internet of Things |
| 1992 | Birth of WWW | 2010 | First 4G handset introduced |
| 1997 | Fiber optic link around the globe | 2012 | 5G focus group created |
| 2005 | YouTube.com launches | 2016 | Coined Industry 4.0 |
| 2006 | Cloud computing started | 2016 | Google unveils Google Assistant |
| 2014 | Demonstration of software-defined networking | 2019 | 6G Communication coined |

**Table 1.**
*Important milestones in wireless and wireline communication.*

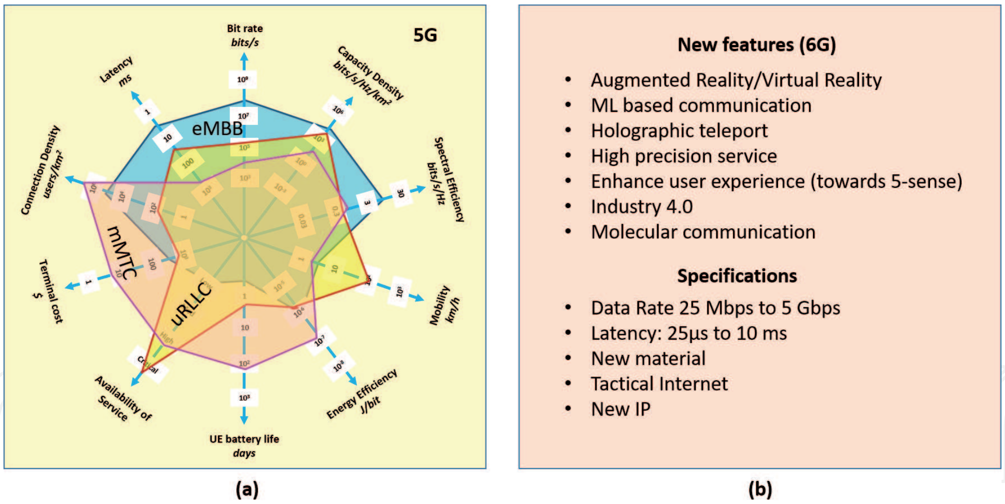


**Figure 1.**
*Characteristics of (a) 5G and (b) 6G communication.*

domains, and finally different backhaul network technologies. The 5G applications categories into three main domains: ultra-reliable low latency communication (uRLLC), massive machine type communication (mMTC), and enhanced mobile broadband (eMBB) [6, 7]. Moving beyond 5G, 6G communication includes few disrupting technologies, such as machine learning (ML) based communication, augmented reality/virtual reality (AR/VR), holographic communication, high precision service, enhance user experience (towards 5-sense), Industry 4.0, molecular communication and more. Their specifications are futuristic, which include 5 Gbps in data rate, 25 µs in latency, new material for 5-sense experience, etc. **Figure 1** provides an overview of the required specifications for three different areas in 5G communication and also in 6G communication [4].

## 2. Technology evolution over the years

In today's telecommunication world, user access the services through different transmission media (copper, wireless, and fiber), however, backbone are predominantly optical. Most of the time, the access network is wireless, as the number of devices increases over the years due invent of IoT). In this work, users use the wireless networks for access purposes with the backbone network as optical. **Figure 2** gives an idea of how the evolution of optical networks makes an impact on the wireless network. As the requirements of high data rate and low latency are increasing, the availability of optical networks (fronthaul) is coming closer to the home and access distance through wireless is decreasing. In the following, the development of technologies will be discussed in both domains.

### 2.1 Development of wireless network

Over the years, wireless communication evolved generation-wise, started from 1G analog to 5G digital and moving towards 6G communication. The focus of 5G and 6G technologies is to connect people, society seamlessly along with applications, services, data, and geographical area in a smart networked environment. The present wireless network is heterogeneous in terms of infrastructure (Macrocell to femtocell), spectrum usage (licensed and unlicensed, sub-GHz to THz), coverage (multi-tier), antenna (single to the massive number of antennas), cooperation (user to eNB), and power usage (mW to 100 W).

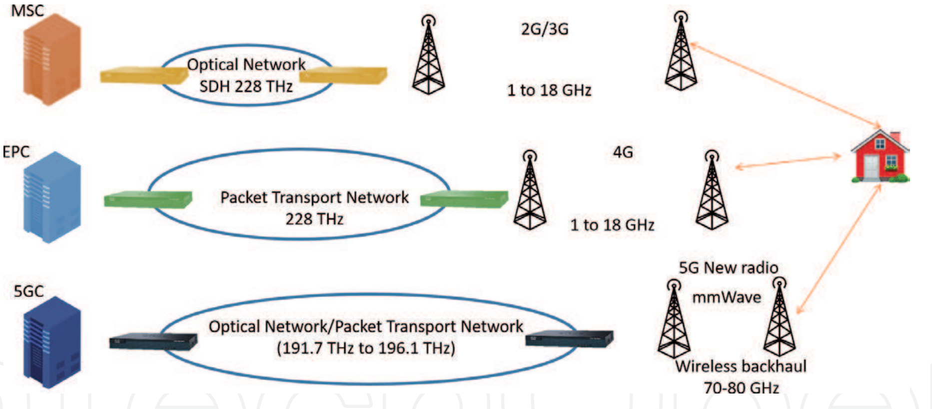


**Figure 2.**
*Impact of the evolution of technologies.*

The technologies developed for supporting these heterogeneous characteristics are co-existing together. These technologies are used to serve their purpose and produce interference on other services while in use, due to this their performance is somehow limited. To enhance performance by increasing awareness and cooperation, 5G technologies proposed several new solutions. These include technologies (as shown in **Figure 3**) like massive multiple-input multiple-output (MIMO) for higher data rate and better coverage, coordinated multipoint transmission (CoMP) for a lower outage, distributed antenna system (DAS) for better connectivity, software-defined radio (SDR) for reconfigurability, cognitive radio (CR) for better spectrum utilization, cloud computing for better usage, software-defined network (SDN) for an optimized network, and mmWave communication for high bandwidth. These technologies differ in channel characteristics, usage specification, operational requirement, application supports, etc. The 5G communication stipulates to support a data rate of more than 5 Gbps, less than 1 ms latency for high mobility users [5]. Several important developments in 5G wireless networks are.

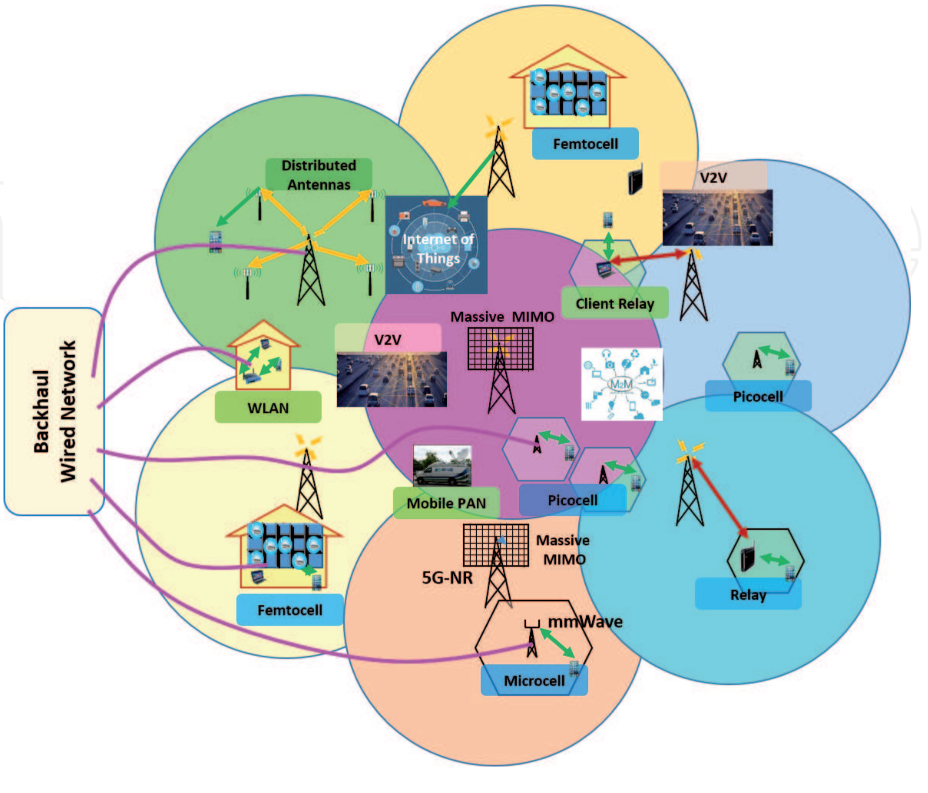


**Figure 3.**
*A typical scenario of a heterogeneous wireless network.*

**5G New Radio**: Even the existence of various radio technologies, 5G communications proposed a completely new radio interface, named 5G new radio (5G NR). The 5G NR interface is a flexible air interface that supports the mainly three ITU defined categories: uRLLC, mMTC, and eMBB. It can also support various other 5G applications such as automotive and health care. 3GPP defined two frequency ranges: FR1 (below 6 GHz) and FR2 (above 24 GHz) [7, 8].

**Massive MIMO**: The 5G communication uses massive MIMO as a promising multi-user MIMO technology, where the number of antennas (more than 100) at eNB is much more compared to traditional systems. This massive number of antennas allows substantial gains in system capacity and energy efficiency of both users and the system. Due to the increasing number of antennas, which guides to a more spatial resolution; subsequently, several users can use the same time-frequency resource. This can eventually lead to large capacity gains [9].

**Non Orthogonal Multiple Access (NOMA)**: Over the year, orthogonal frequency division multiplexing (OFDM) is the most preferred transmission technique. However, a non-orthogonal scheme (NOMA) has been proposed for efficient 5G communication. In NOMA, each user are distinguished by their power levels while operating in the same band and at the same time. It works with successive interference cancelation (SIC) at the receiver uses and with the help of superposition coding at the transmitter, all users can utilize the same and entire spectrum band. The transmitter site superimposed all the individual signals into a single waveform, while the receiver finds the desired signal with the help of SIC decodes mechanism [10, 11].

**mmWave Communication**: Availability of large bandwidth in the millimeter range, 5G & beyond wireless systems proposed to use mmWave communications. The mmWave cites a very short wavelength of the radio frequency spectrum between 24GHz and 100GHz. Due to the much shorter wavelength at millimeter band, it allows the deployment of massive antennas at the transceiver. Thus, the large propagating attenuation due to high frequency will be compensated by using a large antenna array, which provides high gains and finally, provides faster data speeds. In dense deployments scenario, it is also suitable for efficient and flexible wireless backhauling, in addition to supporting ultra-high-speed radio access [12].

**Internet of Things (IoT)**: In the present day, IoT is used almost every possible scenario and application. IoT interconnects different types of devices for various applications and enables machine-to-machine (M2M) communication. BY doing so, it enables data communication between heterogeneous devices automatically without human monitoring and control intervention. Several wireless technologies along with few open standards (Vodafon's Cellular IoT and the NB-IoT by 3GPP) have been used for the deployment of IoT. The 5G will be able to provide a connection to a massive IoT network, where billions of smart devices can be connected to the Internet. Since the 5G networks provide flexible and faster networks, IoT can be easily integrated with the wireless software define networking (WSDN) paradigm [13].

**Coordinated Multipoint (CoMP)**: 5G communication supports small cell and the availability of numerous devices in the environment, makes the network very dense. In the dense environment, intercell interference will be more severe for edge users, which is one of the main reasons for the repeated outage. CoMP transmission technique exploits this interference scenario to enhance the users' performances. CoMP mechanism utilizes the resources more effectively and efficiently by dynamic coordination or transmission and reception with multiple eNBs, which eventually improves the service quality of geographically separated UE and enhances the overall system performance [12].

**Cognitive Radio**: Over the spectrum has been allocated for several usages and the allocated resources are very much under-utilized, To reduce spectrum scarcity and utilize the underutilized spectrum, cognitive radio technology has been proposed. It is an intelligent radio, that can be sense, learn, aware and adapt according to the environment. With the help of software-defined radio (SDR), cognitive radio can be programmed and configured dynamically. SDR is a radio transceiver where radio components (modulators/demodulators, filters, amplifiers, mixers, detectors, etc.) are implemented by software on a personal computer or embedded system [12].

Having understood these technologies of 5G wireless communication, FCN is planning to have the communication system that can achieve data rates of about 100 Tb/s high speed, low latency, and reliable communications are essential for supporting ML/AI at the edge; giving rise to the research field entitled Communication over machine learning. Incorporation of holographic telepresence, holographic communication, virtual reality, and augmented reality in future communication, boost the requirement of wireless communication [14].

### 2.2 Development of optical network

In the present network scenario, the data generated by the wireless devices are transported through an optical network. In general, optical fiber is connected between wireless base stations (BSs/eNB), and their controlling, switching, and monitoring centers. Due to the enormous available bandwidth, the optical fiber can carry data up to 100 Tbps for networking in the optical network. By using appropriate technology, the capacity can be increased further. Similar to the evolution of the wireless network, the optical networks also evolved generation-wise. During the process of evolution, the optical network incorporated optical cross-connect (OXC), a synchronous digital hierarchy (SDH) /synchronous optical network (SONET) rings, optical add-drop multiplexers (OADMs), Software-defined network/network function virtualization (SDN/NFV). Today's long-haul backbone networks of 10/40 Gbps wavelength channels use wavelength-division multiplexing (WDM) transmission systems. Further increase in capacity, the optical network uses a dense WDM (DWDM) frequency grid (12.5, 25, 50, and 100 GHz by G.694.1). Further development of WDM transmission systems makes the system an adaptable DWDM grid.

**Optical Transport Network (OTN)**: ITU-T G.709 defined OTN, which transport digital/optical signal across the core network is a flexible way. Each optical channel carries a separate signal using optical channels multiplexing and uses optical data as a unit. OTN supports the different functions for transporting data, such as multiplexing, routing, management, supervision, and survivability.

**Automatically Switched Optical Network (ASON)**: To accommodate dynamic traffic and their requirements, optical networks need to manage to signal and routing automatically and intelligently. It provides auto-discovery and dynamic connection set-up with the help of dynamic signaling-based over OTN and SDH networks. This is done through a distributed (or partially distributed) control plane, which enables improved support for current end-to-end provisioning, re-routing, and restoration. ASON uses the generalized MPLS (GMPLS) signaling protocol to set up and monitor edge-to-edge transport connections. It also uses single fiber switching to wavelength switching and optical packet switching. The other components, like OXCs, wavelength converters, and OADMs are required for ASON.

**Different variant of wavelength-division multiplexing (WDM)**: WDM is the main transmission technology. Over the year several of its variant has been proposed and used, which are Dense WDM, Coarse WDM, and Time WDM. DWDM uses frequency grids of 12.5, 25, 50, and 100 GHz for transmission. IN the present scenario, many-core networks deployed 1.6 Tbps ( $40\,\text{Gbps} \times 40$ wavelengths) DWDM system. To support the capabilities for 5G and beyond 5G system, the core network will need to transport 10 Tbps or more per fiber which will be pushed further for future FCN.

CWDM combines multiple optical signals at various wavelengths for transmission in optical fiber cables. Up to 18 channels are allowed to be connected over a dark fiber pair. Unlike 0.4 nm spacing for DWDM, CWDM systems have channels at wavelengths spaced 20 nanometers (nm) apart. CWDM works well in two prominent wavelength regions, 1310 nm, and 1550 nm.

TWDM is a WDM technique, where TDMA is applied to a set of wavelengths instead of just one wavelength. It requires strict coordination with the radio equipment to guarantee low latency, as with TDMA and provides more bandwidth than TDMA. In a passive optical network (PON), TWDM can be used as an alternative for transmitting 5G traffic [14].

**Enhanced Common Public Radio Interface (eCPRI) fronthaul**: CPRI is the key internal interface of Radio Equipment (RE), or remote radio head (RRH) and base station unit (BBU) or radio equipment controller (REC) via fronthaul transport network. For fronthaul between RRH and BBU, the overall delay must be limited to less than 100 μs over the multi-hop paths in 5G communication. Due to this stringent latency requirement, eCPRI is becoming an important technology for 5G. Its specification supports more flexibility in the positioning in eNBs, where BBU contains part of the PHY layer and higher layer functions of the air interface, whereas the RRH contains the remaining part of the PHY layer functions and the analog radio frequency functions [15].

**Software-Defined Optical Network**: The SDN paradigm separates the control plane from the data plane and uses an SDN controller for centralizes network control. SDN facilitates NFV for the network virtualization over the physical infrastructure so that multiple virtual networks can operate within. Due to high optical transmission capacities and the specific characteristics of optical components, software-defined optical networks (SDONs) has been proposed. With an underlying optical network infrastructure, SDONs seek to leverage the flexibility of SDN control for supporting networking applications. NFV allows for the flexible operation of multiple virtual optical networks over a given physical optical network infrastructure. SDONs are highly promising for low-latency and high-bandwidth backhauling for 5G eNBs. SDON application layer studies have developed mechanisms for achieving Quality of Service (QoS), access control and security, as well as energy efficiency and failure recovery [16].

**Reconfigurable Optical Add/Drop Multiplexers (ROADM)**: OADM drops the desired wavelengths to local terminals from an incoming multi-wavelength signal by using a wavelength demultiplexer and adds a locally generated wavelength with the remaining pass-through wavelengths to generate the new outgoing multi-wavelength signal. In general, the mux/demux characteristics are fixed. However, to accommodate dynamic behavior and requirements of an optical network, it is almost necessary to have a reconfigurable OADM (ROADM). A ROADM can switch traffic remotely from a WDM system at the wavelength layer and enables the flexibility and reconfigurability of an optical transport network. Having the properties of being colorless (not wavelength selective), directionless (not nodal degree selective), and contentionless (not different wavelength) improves significantly the capacity of add/drop ports in a ROADM [17].

**Software-Defined Optics (SDO)**: Due to dynamic and variable requirements of data traffic, it is almost necessary to do cross-layer interactions. To enables this

SDO has been in an optical network. This can be done through the construction of application-specific protocol stacks out of small reusable services [1].

**Elastic optical network (EON)**: EON accommodates dynamic changes of the optical component, such as flexible wavelength assignment, redefined optical switches and various transponders, etc. to improve system performances. It is possible to integrate EON with an IP layer easily to construct an IP-over-EON. The basic unit of switching in EON is a sub-carrier instead of the wavelength in the fixed-grid case since channels are usually composed of a variable number of sub-carriers [18].

**Software-defined optical transmission (SDOT)**: SDOT supports dynamic reconfigurability of optical components and the ability to adapt various transponders. Softwarization and intelligent control of the data plane facilitates SDOT to optimal use of the available resources, which exploits the multiple dimensions and granularities efficiently.

**Cognitive optical network (CON)**: To make more agile optical networking, a cognitive optical network has been proposed. The CON architecture enables high data rate lightpaths while compensating for a variety of dispersion impairments. CON improves the measuring parameters [e.g., optical signal-to-noise ratio (OSNR), chromatic dispersion (CD), polarization-mode dispersion (PMD), and bit error rate (BER)] while compensates the impairment and subsequently enhance the QoT in the optical network efficiently [19].

## 3. Performance requirement for end-to-end services

Nowadays, end-to-end performance is based on customer experience. As the data is sent over a heterogeneous network combination of wireless and wired (as shown in **Figure 4**), passing through several autonomous systems. These are operated by the same or different operators, which are using various networking technologies. These connections are inter-technical, inter-national, and

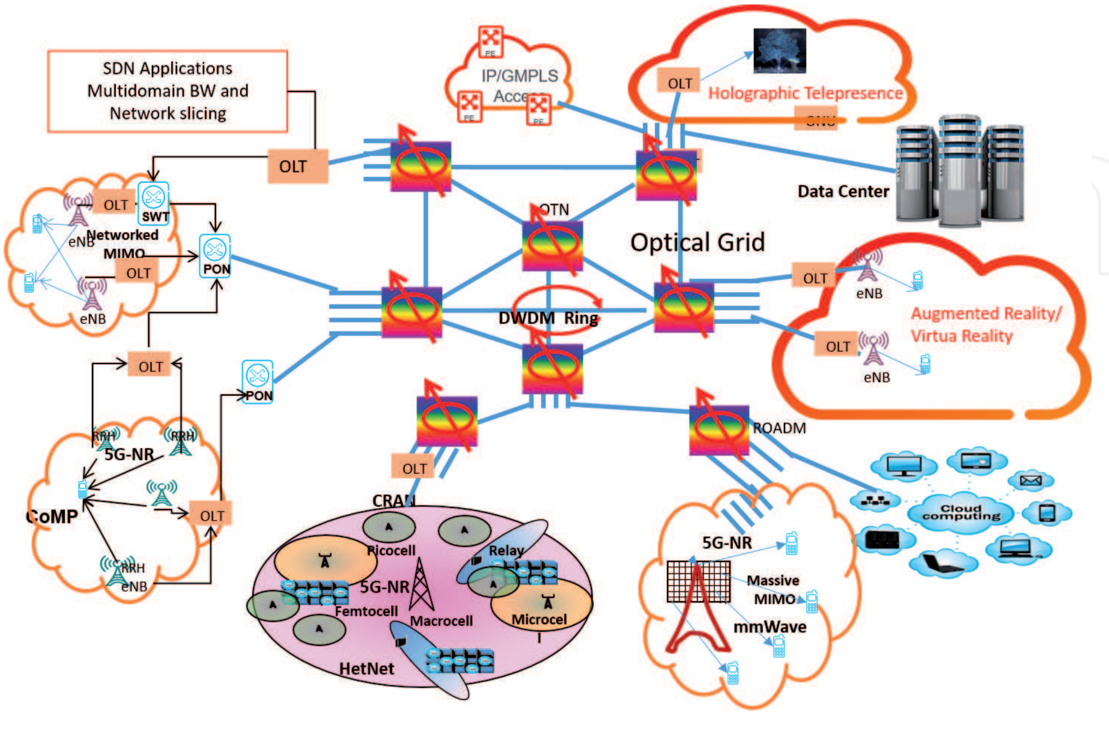


**Figure 4.**
*A typical service architecture of a wireless access network with an optical backbone.*

inter-continental. Thus end-to-end performance is measured by the quality of experience (QoE) along with other metrics like quality of service (QoS), quality of resilience (QoR), quality of transmission (QoT), etc.

QoS/QoE parameters are different for different applications. Varies in latency, connectivity, data rate, etc. QoE evaluation by the user depends on several independent factors, such as service type, user profile (details of user personal information), type of equipment, type of content or service pricing policy (free, paid), screen size, etc. QoE is influenced not only by QoS but also by the grade of service (GoS) and QoR, as shown in **Figure 5**. The most popular measure of QoE is based on the Mean Opinion Score (MOS) [20].

User experience varied QoE while using the service from a different operator. At the technology level, operators are launching new services, which can work with virtualized, software-based, cloud-native, and more agile networks. In general, customer's QoS/QoE needs to be monitored across physical. In virtualized networks, this becomes even more critical where services will be activated in real-time and need to be tested, fulfilled, and assured in an automated fashion.

The specification of 5G communication is different for different applications, like M2M, high broadband, and uRLLC. All these applications have different requirements (see **Figure 2**). Apart from these, in 6G communication, several new applications have been proposed, such as holographic telepresence, AR/VR, etc. The transmission requirements of these applications are quite futuristic in terms of data rate, latency, and BER. Thus, maintaining QoE in FCN will be very complex and challenging, as there are different types of CoS asking for separate GoS working in various environments, policies, and networks.

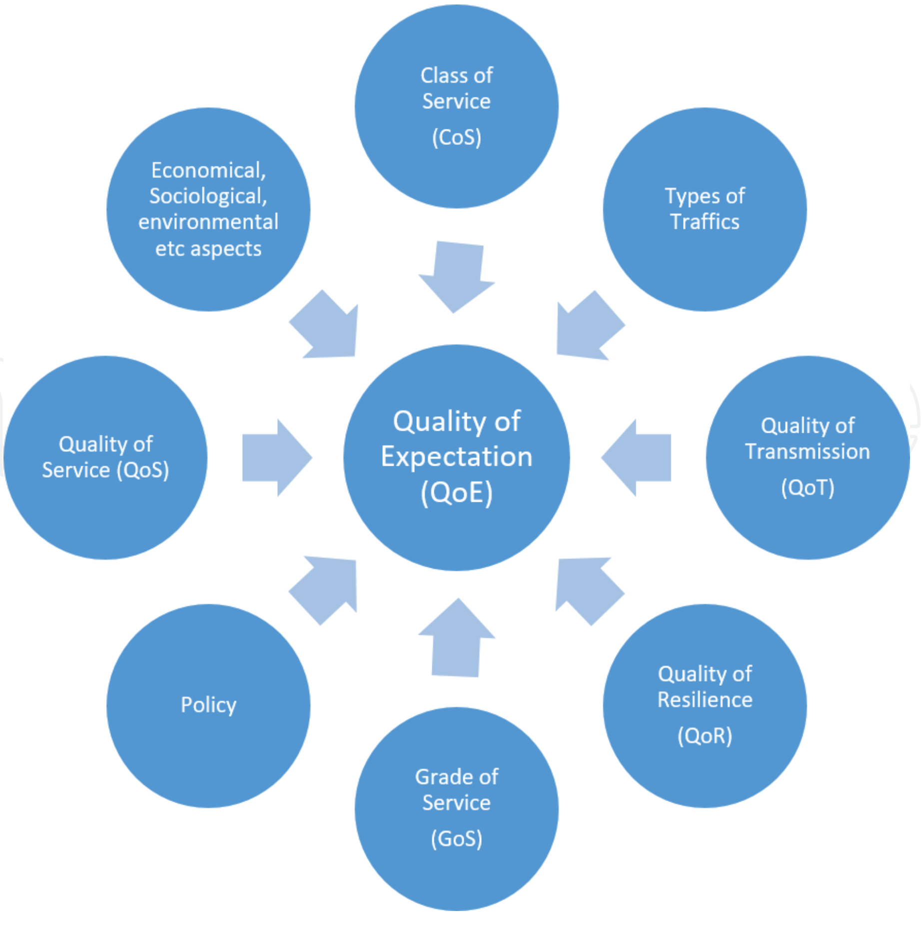


**Figure 5.**
*Factors influencing QoE.*

## 4. Behavior of evolved wireless technologies with corresponding evolved optical techniques to satisfy user QoE

In the present day, users require appropriate supports from the network infrastructure as per the service usages. In general, users are connected to the network through wireless access and the wireless access point is connected to the optical fronthaul node. Depending on the application, the user required variable BW, the latency of wireless access to satisfy its QoE. Optical network technologies will play an important role in addressing these requirements within the radio access network (RAN). Through the deployed network technologies, such as backhaul networks, metro networks, and PONs, etc., optical networks continuously support their QoS. The optical network used an eCPRI fronthaul interface to support the 5G specification. For example, eCPRI of 100 Gb/s supports a 5G system of 200 MHz BW (below 6 GHz frequency) with 64 (8X8) antenna arrays. It can also support mmWave communication of 400 MHz radio bandwidth in 60 GHz frequency range with 256 (16x16) radiating elements by 400–800 Gb/s capacity [21, 22].

**Support IoT Applications**: I0T is one of the widely used technology in recent times, which is used in a wide variety of applications. The use of IoT appears to be most challenging due to the wide range of different devices, various options of network connectivity, different protocols, methods, etc. It provides support to users with smart services while raising security and privacy threats [23]. The threat becomes challenging while users and networks are heterogeneous. To support this heterogeneity in IoT, SDO provides an appropriate solution. A solution like cognitive radio and CON can work together to facilitate the dynamic behavior and requirements of diverse IoT applications. Apart from this, SDN, wireless-SDN and SDON are also participating to support IoT services, while using edge router to integrate into the network.

**Reduce outage of edge users**: To reduce the outage of edge users, successful operation of CoMP is necessary, which depends on very fast and highly reliable feedback between the user and eNBs on the channel condition. At the same time, all the eNBs need to be synchronized and data should be present at all eNBs in real-time. Connecting optical fiber link between eNBs should ensure this low latency level as per 5G standard through the fast feedback channel. This is more complex, challenging when the number of participating eNBs is more, and the traffic load of the network increases. These will impact on processing (impact on delay in data transmission), synchronization (impact on a real-time mismatch), which depends on deploying sites topology, backhaul latency, and capacity [23].

**Flexible Integration of data traffic**: In 5G and 6G wireless communication, the data traffic has a diverse specification and has a wide variety of requirements. To support these dynamic and diverse requirements, flexibility and adaptability should be supported by an optical network. Optical networks supported these flexible and elastic nature by using SDN/NFV. Integration of optical components, such as various variants of ROADMs, OXC in multi-layer SDN makes network towards SDON. The use of different switching paradigms and a combined implementation of the switching elements in electronics and optics (hybrid optical switching) in SODN, can lead to even higher flexibility and better transmission efficiency [24].

**Integration to heterogeneity**: To support the requirement of 5G, the standards like NG-EPON (by IEEE) and G.hsp.x (by ITU-T) are proposed. Coexistence of 10G PON channels for residential, 100G dedicated channel for business along with wireless fronthaul, supports heterogeneity of 5G & beyond 5G communication. These are supported by long reach TDM-DWDM PON system, with up to 100 km reach, 512 users, and an emulated system load of 40 channels, employing amplifier nodes with either erbium-doped fiber amplifiers (EDFAs), or Raman amplifier or semiconductor optical amplifiers (SOAs). This end-to-end support by SODN with help of PON physical layer along with dynamic wavelength allocation (DWA) in response to increased traffic demand [25].

**Service on the fly**: Providing service through the cloud is immensely popular among users. The 5G communications also advocate and support the application through the cloud and aim to provide them effectively and efficiently. The Cloud-RAN (C-RAN) approach for 5G wireless splits the radio processing chain to simplify the processing. To optimized support for different technologies, levels of centralization, and deployment options in 5G, EONs offer large degrees of flexibility, adaptability, and programmability in different dimensions. EON provides granular spectrum width consisting of variable numbers of sub-carriers as the demand and deployment technology to support 5G disruptive capabilities, technologies, and use cases. It allows both digital and analog signals to be transported and switched over the same optical fiber, thus facilitating technologies such as mm-wave. Besides, the EON can tune signal properties (e.g., modulation format, bit rate, optical reach, and so on) to cope with the constraints of deployed technologies and different requirements of use cases [26, 27]. Hence, it can provide a much larger bandwidth and more variety of bit rates on an optical fiber.

**Enabling Artificial intelligence (AI)**: In the present times, AI has taken center stage in all kinds of research and development. To provide better support, monitor, and control, every kind of service uses AI technology. AI will learn with the help of a machine learning algorithm for better service. AI and machine learning is the main technology of 5G and 6G communication. Wireless and optical networks use these technologies extensively. Specifications like high speed, low latency, and reliable communications are essential for supporting ML/AI at the edge. This can bring mobile edge computing to AI-at-the-edge [28, 29].

**Energy Consumption**: As the requirements are increasing to satisfy enhance throughput, latency & other QoS for different classes of traffic, applications, services, and QoE, energy consumption is increasing in the network. The usage of massive MIMO, dense network, heterogeneous network with small cells along with billions of devices increases the power consumption in the network, which increases the greenhouse effect. 5G power consumption at peak hours is 1200 W to 1400 W, which is 300–350% greater than of 4G [30]. However, to work in an energy-efficient way, network wire-line, wireless and core networks) are using the resources in an optimized way, which motivates the network to use different tradeoffs in protocol layers [31], which varies from infrastructure (dense network) to device (visual resolution). A green framework has been proposed for energy-efficient communication in a wireless network with the energy-cognitive cycle, where the awareness is categorized as network awareness and access point awareness module [32].

Every component of the optical network participated in the data transports and consumes energy. The CAPEX amount is more at the beginning, however, usage of massive MIMO along with small cells in dense networks can impact more on OPEX. Usage of NFV decreases the OPEX costs by reducing the conventional purposed hardware, installation, and up-grading for new services and Virtual network functions (VNF) are virtualized tasks implemented by the NFV platform, providing security, load balancing, and other EPC functions [33]. A WDM transmitter/receiver (TX/RX) pair at the interface between each link provides regenerated signals at each wavelength for injection in the next link of the system. Energy consumption exists at many levels in optical transmission systems, from inefficiencies at the device level in optical amplifier pump lasers and their cooling systems, at the circuit level in the tradeoff of efficiency for speed in high-speed electronic circuits used in transmitters and receivers, and at the system level in terms of multiplexing and management overheads [34, 35].

## 5. Conclusion

This chapter provides an overview of telecommunication networks while considering both wireless and optical networks. The technologies in both the networks were evolved in such that they can assist each other for better performance of users and network as a whole. The chapter provides an overview of the main technologies in 5G and analyses how the optical network technologies are beneficial and cooperative to wireless technologies.



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