A Millimeter Wave over High Speed Next Generation Passive Optical Network Stage2: A Notion for Future Generation Network

Harpreet Kaur

Assistant Professor
Department of School of Computational Sciences
GNA University Phagwara, Punjab India.

Abstract-- **The potential of millimeter wave to support high speed next-generation passive optical network (NGPON2+) technology is covered in this research. Millimeter wave offers optical access networks a number of benefits, including higher capacity, better spectrum usage, decreased latency, and improved security. The study goes on to look at the difficulties that need to be overcome in order to fully utilize millimeter wave for NGPON2, such as the requirement for higher data rates, expanded transmission range, and enhanced antenna performance. The report concludes with a summary of the various millimeter wave enabled high speed NGPON2 components and the ongoing research to improve their performance.**

Index Keys-- **5G, Millimeter wave, Passive Optical Network, Next Generation Passive Optical Networks 2.**

1. INTRODUCTION

A new generation of fiber-optic access networks called Next Generation Passive Optical Networks (NGPON2) claims to offer previously unheard-of levels of bandwidth, speed, and cost effectiveness. It is anticipated that this will be the way that broadband access develops moving forward and will offer a platform for the delivery of cutting-edge services including voice, data, and video. A single Optical Network Terminal (ONT) can link numerous customers to the network using the point-to-multipoint network architecture that underpins NGPON2. This architecture provides service delivery flexibility while also streamlining the network architecture and lowering implementation costs. The foundation of NGPON2 is the standardization of PON technology. It is an improvement on the GPON (Gigabit PON) technology now in use, which was the first PON standard to be put into use.

The demand for bandwidth and internet subscribers worldwide is one of the biggest problems of today. The Time and Wavelength Division Multiplexing-Passive Optical Network (TWDM-PON) has become a key driving technique under the standard ITU-T G.989 for the NGPON2 that takes this technology to the next level[1] It has emerged as a most prominent solution to accommodate the large number of rising mobile subscribers by providing the large bandwidth. It is the descendent of two versions of PON known as Gigabit-PON (GPON) and 10G-PON, and it inherits all of their qualities. It has shown itself to be very capable of transmitting multiple wavelengths at a rate of 40 Gbps via single-mode fiber; in the future, 80 Gbps will be feasible. In addition to its high data transmission rate, NGPON2 also offers a number of other benefits. It provides the ability to support more advanced services such as multimedia, VoIP, and IPTV[1][2]. It also offers improved security, scalability, and reliability, making it ideal for mission-critical applications. Furthermore, it provides significant cost savings due to its lower deployment and maintenance costs.

Faster speeds, more dependability, and reduced costs might revolutionize broadband access thanks to the technology. As a result, it is anticipated that NGPON2 will be adopted by a large number of service providers soon. The ITU-T series-G.989 standard's TWDM-PON method is used by the hybrid network's NGPON2 to deliver the aforementioned functionalities[3][4]. NGPON2 is more suited for and promises to facilitate the 5G fronthaul (FH) network (ODN) since it connects optical line terminal (OLT) and optical network units (ONUs) via the identical fiber, or optical distribution network. In order to handle the rise in smartphone users and network traffic, NGPON2 FH offers a total transmission rate of 40Gb/s that is uniformly distributed over 4 pairs of fibers with a 20km length, whether upstream or downstream[5]. NGPON2 has a variety of drawbacks in addition to its advantages. For instance, it necessitates the time- and money-consuming installation of new gear and software. Additionally, because the technology is so complicated, it necessitates intensive training for technicians and service providers, which can result in errors and service delays. The installation of specialized equipment is also necessary, which raises the deployment cost even more. Despite these constraints, high-speed NGPON2 can use data transfer rates up to 40Gb/s or more[6][2] due to its greater split ratio, more waves, and coverage of more than 100km.

Now NGPON is required more bandwidth and data to keep up with rising demand as mobile subscriber growth continues. Up to this moment, PON technology has been used commercially thanks to the IEEE and ITU-T specifications[7][8]. Then ITU-T has begun work on a high-speed project for the G.9084.3 series that uses a single wave carrier signal with a 50 Gbps rate to assist in reducing the cost of OLTs. The costs of deployment rise when various distinct wavelengths are combined. One of the key components of the 5G network, which is expanded up to 60 km under the ITU-T standard, is FH distance. Additionally, the 50G high speed network's downstream and upstream band plans are being looked into. In place of upstream ranges like 1268 nm to 1272 nm and 1298 nm to 1302 nm that are being considered, a wavelength range of 1340 nm to 1344 nm is recommended for downstream[9]. Therefore, high speed NGPON2+ can be an option that is adopted by the ITU-T G.9084.3. Millimeter wave over

TWDM for FH has been used by utilizing the concept of 50G-PON to study network capacity at the 200Gb/s transmission speed for both up and downlink across the 60km long fiber[10].
It is anticipated that many service providers will adopt it in the near future despite the difficulties involved in its deployment since the potential advantages are too tremendous to pass up. Long-distance transmission has been made possible by numerous approaches, including Ethernet-PON, Gigabit-PON, Orthogonal Frequency Division Multiplexing (OFDM), etc., but at the expense of data rate (2.5-10Gb/s), split ratio (1:16-1:64), and multiplexing techniques like TDM, TDMA[6]. In the end, research in millimeter wave over fiber and NGPON2+, is required. In order to successfully satisfy the objectives of the bank for 5G and beyond while utilizing the limited resources available, the suggested research aims to investigate 5G FH networks over the 50G-PON network[11][12] Here, the focus will also be on looking at various long-reach solutions with high data rates and capacity, enabling mobile users to use the internet whenever they want without worrying about congestion. The limit is raised to meet the large number of users.

2. MILESTONE APPROACHES

The combination of 50G-PON and NGPON2 technology represents a significant development in optical networking that can handle the rising needs of contemporary communication networks. While NGPON2 offers an adaptable and scalable foundation for optical access networks, 50G-PON is a development of established PON technology that aims to deliver higher data speeds[13][14]. Together, they provide the following benefits:

- ***Improved Bandwidth:*** As 50G-PON and NGPON2 are combined, the bandwidth is significantly increased as compared to earlier PON technologies. Supporting the rising demand for high-speed internet, multimedia streaming, and data-intensive applications is essential[13].
- ***Symmetric and Asymmetric Speeds:*** The adaptability of NGPON2 enables either symmetric or asymmetric data rates, meeting the various needs of residential and commercial users. Regarding the various needs of 5G, IoT, and cloud-based services, this is especially helpful[3].
- ***Several Wavelengths:*** NGPON2 offers a variety of wavelengths, which 50G-PON can further improve. With the help of network slicing—the creation of various virtual networks within the same infrastructure which enables efficient utilization of resources and service differentiation multi-wavelength capability is made possible[15][14].
- ***Low Latency:*** A low latency is essential for 5G networks, particularly for applications like real-time communication and autonomous vehicles. The requisite low-latency transport for these applications can be delivered using 50G-PON and NGPON2.
- ***Quality of Service:*** High data speeds provided by 50G-PON and the QoS characteristics of NGPON2 allow network operators to efficiently prioritize traffic. For a wide range of applications to receive consistent service quality, this is crucial[9].
- ***Security:*** It is crucial because 5G networks enable sensitive data and important services. Advanced authentication and encryption techniques can be incorporated by NGPON2+50G-PON to safeguard the integrity of data and user privacy[16].
- ***Smooth Migration:*** The combined implementation of 50G-PON and NGPON2 should offer a seamless migration route from conventional PON technologies, ensuring that legacy ONUs can cohabit and interact with newer hardware, minimizing disturbance for service providers and clients[17].

For contemporary optical access networks, combining 50G-PON technology alongside NGPON2 offers a strong solution that can deliver enormous bandwidth, minimal latency, and the versatility needed to serve a variety of applications as well as services in the 5G era and beyond.

3. MILLIMETER WAVE

For efficient use of the high spectrum frequency band and to sate the desire for bandwidth, the 5G FH transmission using the same fiber is interoperable with millimeter-wave ranges between 30-300GHz[11]. This millimeter wave spectrum band is depicted in Figure 1. Due to its potential to completely alter the communication landscape, millimeter-wave over fiber is a technique that has been receiving a growing amount of attention in recent years.

Fig.1. Band of millimeter waves for 5G [12].

The ability of millimeter-wave over fiber to carry millimeter-wave signals through optical fibers is what gives it its potential[8]. Millimeter compared to their lower-frequency counterparts, millimeter waves, which are electromagnetic waves with a frequency higher than that of microwave radio waves more commonly used in communication, have various benefits, including a wider bandwidth and a reduced attenuation loss when penetrating things. The advantages of millimeter wave can be realized without the use of pricey and challenging-to-install microwave radio equipment by transmitting these signals with greater frequencies across optical fibers[18][19]. The three main components of a millimeter wave over fiber system are a laser source that has been particularly created, an optical fiber, and a receiver. An optical fiber is utilized to transmit the millimeter wave signal produced by the laser source[19][20]. The receiver on the other side of the fiber is used to pick up the signal and transform it into useful data. The system's core is enveloped by a variety of additional parts that are utilized to enhance the system's performance, including a power supply, amplifiers as well as filters, and additional signal processing parts.

4. MILLIMETER WAVE OVER NGPON2+

Several modulation approaches, including non-return to zero, cross-phased, four-wave mixing, etc., are suggested to investigate in order to combine the NGPON2+ and radio over fiber concepts for full-duplex to modulate millimeter wave at speeds of 50 Gbps per signal and coverage area from 20 to 60 km. Figure 2 depicts the enlargement of NGPON+ and millimeter wave[10]. The benefit of millimeter-wave over fiber is that non-line-of-sight and route loss is avoided. The newest fiber optics technology, millimeter wave over NGPON2, promises to transform communication.

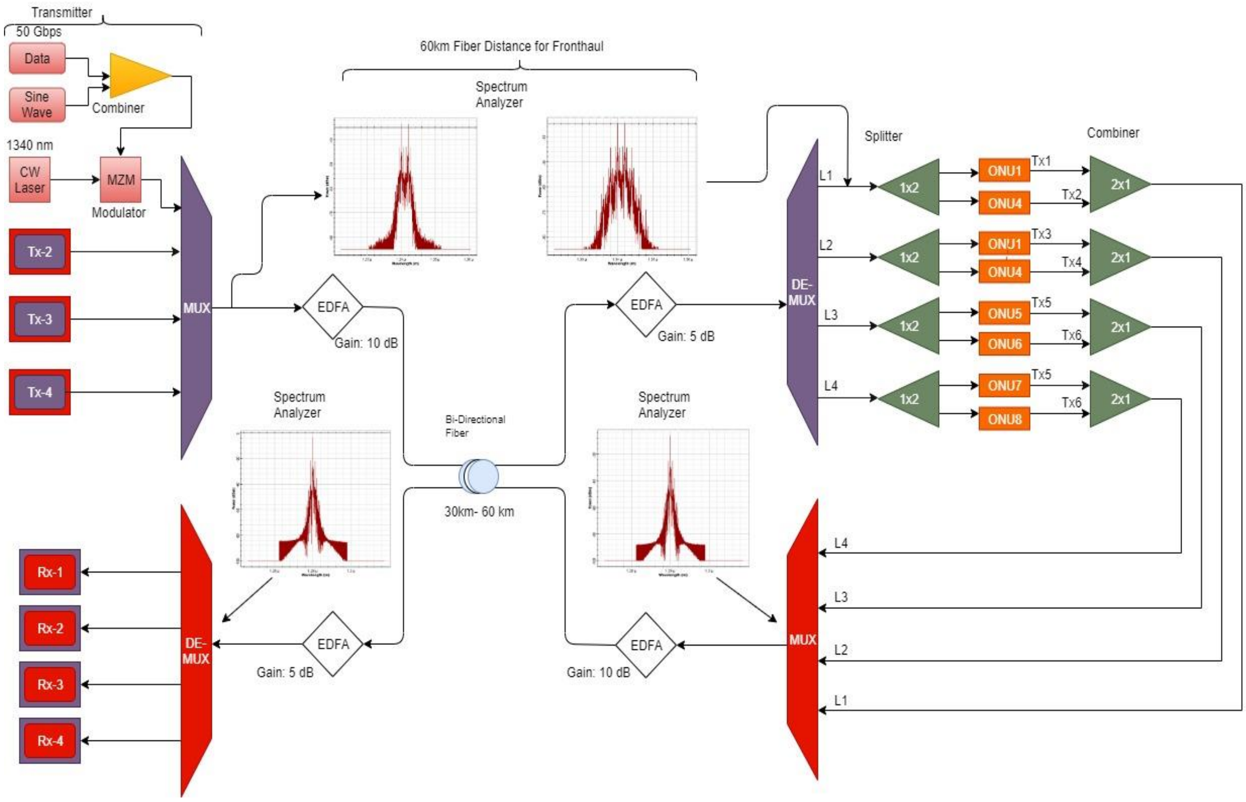

Fig.3. Structure of millimeter wave over NGPON2[10].

With the objective to provide exceptionally high-speed internet connectivity for both home and commercial consumers, this technology is currently being developed. High-speed, low-latency internet connectivity over a single fiber optic connection is what this technology aims to give. A ground-breaking technique, millimeter wave over NGPON2+ uses millimeter waves to transmit massive volumes of data over just a single fiber-optic line. For both residential and commercial consumers, this sort of technology is currently being developed to offer extraordinarily high-speed broadband connections. It could deliver speeds of 50 Gbps per signal, which would be faster than current broadband technologies[10]. Data is sent via a single fiber optic connection utilizing millimeter-wavelength light with this technique. Since this wavelength is substantially shorter than the one currently utilized by fiber optic networks, much higher data speeds can be achieved. Residential and commercial clients will be able to enjoy this technology's incredibly high-speed broadband[13]. The technology is being designed to operate on current fiber-optic lines, so it may be used without the addition of new infrastructure.

5. CHALLENGES

A recently developed technology called millimeter wave is being used in 5G networks, and it is anticipated to offer a range of services and applications, including those with extremely low latency and large capacity. It does, however, also come with certain difficulties. As a result of the millimeter wave frequency range being significantly greater than the range utilized for earlier generations of cellular networks, communications will be more vulnerable to disruption, attenuation and other physical impediments. This frequency range ranges from 24 to 86GHz[21]. The fact that millimeter wave signals have a substantially less range than lower frequency signals is one of the technology's biggest hurdles. This implies that in order to serve the users, a single base station's coverage area must be substantially greater. Another problem is that physical obstacles like buildings, trees, and other barriers can easily block millimeter wave transmissions. This makes it challenging to offer dependable coverage in regions with a lot of physical barriers, like urban settings.

It will be difficult to use millimeter wave technology on current networks like NG-PON2+. Although NG-PON2+ is intended to accommodate a 50 Gbps single signal rate, a variety of traffic kinds, and the inclusion of millimeter wave signals, upgrades to the current infrastructure might be necessary. The rapid deployment of millimeter wave technologies on existing networks can be expensive and challenging. In conclusion, there are several difficulties with the implementation of millimeter wave technology over NG-PON2+ networks. The necessity for wider coverage areas, the vulnerability of the transmissions to disturbance and obstruction, the requirement for more sophisticated antennas and receivers for communication, and the possibility of expensive and time-consuming upgrades to the current infrastructure are a few of these. Despite these difficulties, millimeter wave technology is anticipated to be crucial to the development of 5G networks. These difficulties can be resolved as the technology develops, allowing the millimeter wave's advantages to be reaped. Below is a discussion of several significant difficulties:

- ***Advancement and Interoperability:*** The advancement and standardization of 50G-PON technology as well as assuring equipment interoperability across many vendors provide a considerable hurdle. Collaboration amongst industries is essential to creating a standard foundation for 50G-PON[22].
- ***Cost:*** Upgrading optical infrastructure, such as OLTs and ONUs, is a significant upfront expense for deploying 50G-PON networks. A key factor for service providers is the adoption of 50G-PON's cost-effectiveness[9].
- ***Complexity:*** Wavelength control and multiplexing/demultiplexing are two areas where TWDM-PON brings complexity. Technical difficulties include managing several wavelengths, maintaining their stability, and preventing crosstalk[1].
- ***Wavelength Distribution:*** In a TWDM-PON system, effective wavelength allocation and management are crucial for maximizing network capacity. It can be difficult to dynamically allocate wavelengths while avoiding interference to satisfy shifting bandwidth demands[23].
- ***Power Budget:*** It's critical to ensure that the TWDM-PON system has enough power allocated for each wavelength. Keeping power budgets under control while reducing signal deterioration becomes more difficult as the variety of wavelengths rises[1].

To ensure the successful installation and operation of 50G-PON employing TWDM-PON technology, addressing these issues would require continued collaboration among industry players, research and development activities, adherence to norms, and creative solutions.

6. FUTURE SCOPE

The coming generations of 5G networks heavily rely on millimeter wave technology, and NGPON2 represents one of the technologies that have the greatest potential to make these networks possible. Since the 1980s, millimeter wave technology has been employed in wireless communications systems, but due to the substantial propagation losses associated with the frequencies, it has only been used for short-range applications. For longer-range applications like 5G cellular networks, there has been growing interest in millimeter wave technology in recent years. This is because millimeter wave frequencies have the capacity for large bandwidths and are less crowded. The development of NGPON2 has made it possible to construct millimeter wave networks over vast distances. Despite using a different modulation method to provide faster data speeds and wider coverage, it is founded on the same fundamental ideas as passive optical networks.

The key benefit of NGPON2 for millimeter wave networks is that it offers an affordable method of deploying millimeter wave networks across great distances. NGPON2 does not need pricey base stations or backhaul cables, in contrast to conventional networks. Instead, a single fiber link between two places can be used to deploy the network, making it possible to do so affordably. Furthermore, NGPON2 can deliver data rates that are far higher than those of conventional networks, enabling the implementation of fast connectivity data services over vast distances[24]. The fact that NGPON2 continues to be in its early phases of development and that numerous technical issues need to be resolved prior it can be used in actual networks is one of its major drawbacks. Deployment costs due to aggregation of multiple wavelengths are also another consideration for NGPON2, and other suppliers have created their own proprietary solutions[1]. Interoperability problems between several suppliers may result from this. Despite the difficulties, NGPON2 has a lot of promise to support the installation of millimeter wave infrastructure for 5G.

NGPON2+, which implements the idea of 50G-PON and millimeter wave for 5G fronthaul and beyond, coinciding with the changing needs of next-generation networks. The numerous and demanding applications that 5G and subsequent networks will enable will largely be supported in large part by its capacity to deliver enormous bandwidth, low latency, and increased QoS[25][26]. Realizing the full capabilities of NGPON2+ in the changing telecoms landscape will depend on collaboration between industry leaders, continued development and research, and adherence to standards. With high spectrum bands, the emerging technologies 100G, 200G, or THz will be the communications network's future face for generations beyond the current ones[27].

7. CONCLUSION

Overall, millimeter wave over fiber systems is a desirable alternative for many applications due to their significant benefits over conventional radio systems. They are a wonderful fit for many applications since they are far more affordable, simpler, and dependable than conventional radio systems. More and more people are starting to understand the possibilities of millimeter wave over fiber systems as the technology advances and become more publicly accessible, and the communication landscape will undoubtedly be revolutionized as a result. An innovative technology that has the potential to completely change how we communicate is a millimeter wave over NGPON2+. It has the ability to lower the price of broadband connection for consumers while also offering extremely high-speed broadband connectivity to residential and commercial clients. Additionally, it is being created to operate over currently installed fiber-optic connections, so it may be adopted without requiring for additional infrastructure. As a result, users can benefit greatly from this technology because it can lower the price of broadband connection while rendering it more accessible. Future communications and broadband access will undoubtedly be significantly impacted by this technology.

REFERENCES:

[1] M. A. Abdulnabi, W. Kadhim Saad, and B. J. Hamza, "Performance Analysis of Full-Duplex NG-PON2-RoF System with Non-linear Impairments," *J. Phys. Conf. Ser.*, vol. 1530, no. 1, 2020, doi: 10.1088/1742-6596/1530/1/012158.

[2] T. Lagkas, D. Klonidis, and P. Sarigiannidis, "5G / NGPON Evolution and Convergence : Developing on Spatial Multiplexing of Optical Fiber Links for 5G Infrastructures 5G / NGPON Evolution and Convergence : Developing on Spatial Multiplexing of Optical Fiber Links for 5G Infrastructures," *Fiber Integr. Opt.*, vol. 00, no. 00, pp. 1–20, 2020, doi: 10.1080/01468030.2020.1725184.

[3] S. Rajalakshmi and T. Shankar, "Investigation of different modulation formats for extended reach NG-PON2 using RSOA," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 12, pp. 142–149, 2019, doi: 10.14569/ijacsa.2019.0101220.

[4] D. Nesset and H. Technologies, "Pr E oo f," no. March 2015, 2016, doi: 10.1109/JLT.2015.2389115.

[5] I. Systems, "ITU-T," 2015.

[6] T. Horvath, P. Munster, V. Oujezsky, and J. Vojtech, "Activation process of ONU in EPON/GPON/XG-PON/NG-PON2 networks," *Appl. Sci.*, vol. 8, no. 10, 2018, doi: 10.3390/app8101934.

[7] M. I. Anis, M. S. Qureshi, and S. Zafar, "Demonstration of TWDM-PON Backward Compatibility with Conventional GPON," *Wirel. Pers. Commun.*, vol. 95, no. 2, pp. 581–592, 2017, doi: 10.1007/s11277-016-3911-7.

[8] D. T. Van Veen and V. E. Houtsma, "Symmetrical 25-Gb/s TDM-PON with 31.5-dB optical power budget using only off-the-shelf 10-Gb/s optical components," *J. Light. Technol.*, vol. 34, no. 7, pp. 1636–1642, 2016, doi: 10.1109/JLT.2016.2518998.

[9] ZTE, "White Paper on 50G-PON Technology," 2020.

[10] H. Kaur, S. Singh, R. Kaur, and R. Kaur, "50G-next generation passive optical networks stage 2 using millimeter wave over fiber technique under the ITU-T G.9804 standardization," *Opt. Quantum Electron.*, vol. 55, no. 5, pp. 1–15, 2023, doi: 10.1007/s11082-023-04732-w.

[11] P. Goel and R. Kaushik, "Performance Analysis of 80 GHz-Millimeter Wave Radio over Dispersive Fiber," *J. Opt. Commun.*, 2019, doi: 10.1515/joc-2019-0103.

[12] "5G mmWave_ NSA or SA_ - 5gmmwave."

[13] D. Zhang, D. Liu, X. Wu, and D. Nesset, "Progress of ITU-T higher speed passive optical network (50G-PON) standardization," *J. Opt. Commun. Netw.*, vol. 12, no. 10, p. D99, 2020, doi: 10.1364/jocn.391830.

[14] G. V. Arévalo, R. C. Hincapié, and R. Gaudino, "Optimization of multiple PON deployment costs and comparison between GPON, XGPON, NGPON2 and UDWDM PON," *Opt. Switch. Netw.*, vol. 25, no. March, pp. 80–90, 2017, doi: 10.1016/j.osn.2017.03.003.

[15] "Latest progress of 50G PON (Passive Optical Network) technology in 2021."

[16] J. Prat, J. A. Lázaro, K. Kanonakis, and I. Tomkos, "New FTTH architectures for NG-PON-2," *Opt. InfoBase Conf. Pap.*, no. June, pp. 2–4, 2010, doi: 10.1364/anic.2010.atua4.

[17] B. Li *et al.*, "DSP enabled next generation 50G TDM-PON," *J. Opt. Commun. Netw.*, vol. 12, no. 9, pp. D1–D8, 2020, doi: 10.1364/JOCN.391904.

[18] Anand Prem P K and Arvind Chakrapani, "Optical Millimeter Wave Generation - A Research Perspective," no. February, pp. i–xii, 1–79, 2017.

[19] H. Zhou, Y. Shen, M. Chen, J. Cheng, and Y. Zeng, "A ROF Access Network for Simultaneous Generation and Transmission Multiband Signals Based on Frequency Octupling and FWM Techniques," *Adv. Condens. Matter Phys.*, vol. 2018, 2018, doi: 10.1155/2018/9409583.

[20] T. R. Raddo, S. Rommel, B. Cimoli, and I. T. Monroy, "The optical fiber and mmwave wireless convergence for 5G fronthaul networks," *IEEE 5G World Forum, 5GWF 2019 - Conf. Proc.*, no. 2019, pp. 607–612, 2019, doi: 10.1109/5GWF.2019.8911613.

[21] D. Konstantinou *et al.*, "5G RAN architecture based on analog radio-over-fiber fronthaul over UDWDM-PON and phased array fed reflector antennas," *Opt. Commun.*, vol. 454, no. August 2019, p. 124464, 2020, doi: 10.1016/j.optcom.2019.124464.

[22] "50G PON Takes A Step Closer to Reality as ITU-T Standard Achieves Consent."

[23] Y. Luo *et al.*, "Time- and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation PON stage 2 (NG-PON2)," *J. Light. Technol.*, vol. 31, no. 4, pp. 587–593, 2013, doi: 10.1109/JLT.2012.2215841.

[24] S. Liang, F. Zhao, and W. Jiang, "Optical Fiber Technology A learning algorithm for TWDM-PON ' DWBA with 5G fronthaul networks," *Opt. Fiber Technol.*, vol. 53, no. October, p. 102039, 2019, doi: 10.1016/j.yofte.2019.102039.

[25] W. Zhou and C. Qin, "Simultaneous generation of 40, 80 and 120 GHz optical millimeter-wave from one Mach-Zehnder modulator and demonstration of millimeter-wave transmission and down-conversion," *Opt. Commun.*, vol. 398, no. April, pp. 101–106, 2017, doi: 10.1016/j.optcom.2017.04.043.

[26] T. R. Raddo *et al.*, "Transition technologies towards 6G networks," *Eurasip J. Wirel. Commun. Netw.*, vol. 2021, no. 1, 2021, doi: 10.1186/s13638-021-01973-9.

[27] W. Lee *et al.*, "Coherent terahertz wireless communication using dual-parallel MZM-based silicon photonic integrated circuits," *Opt. Express*, vol. 30, no. 2, p. 2547, 2022, doi: 10.1364/oe.446516.