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G.654.E Fibre Technology Application Report

Participating organizations:

Yangtze Optical Fibre and Cable Joint Stock Limited Company, China United Network Communications Group Co., Ltd., China Mobile Communications Group Co., Ltd., China Telecom Corporation Limited, State Grid Information & Telecommunication Center (Big Data Center) , China Academy of Information and Communications Technology, and Nokia Shanghai Bell Co., Ltd.

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Chapter 1 Overview

With the widespread adoption of emerging technologies such as 5G, Artificial Intelligence (AI), Internet of Things (IoT), and high-definition video streaming, global data traffic has experienced explosive growth. New demands are being placed on optical transmission networks regarding architecture, bandwidth, services, and latency. These developments necessitate the transformation and upgrading of optical networks to establish an all-optical infrastructure capable of supporting computing power. Additionally, critical scenarios such as high-frequency financial trading, real-time cloud video conferencing, autonomous driving, industrial automation, and power relay protection are extremely demanding for real-time data transmission, creating a need for low-latency communication networks. Similarly, long-haul, highly reliable communication links are urgently required for applications like multinational enterprise data synchronization and global internet service interconnection. Moreover, communication networks must demonstrate excellent environmental adaptability to ensure the integrity and security of data transmission in complex electromagnetic environments and extreme weather conditions. Collectively, these requirements define the modern communication network's needs: high bandwidth, large capacity, low latency, long-distance transmission, and high reliability[1-3].

As data transmission demands and bandwidth pressures on traditional carrier networks continue to surge, backbone networks are rapidly evolving with transmission rates accelerating from 100G to 400G and beyond. To future-proof high-speed information infrastructure, proactive deployment of optical fibres and cables supporting 400G+ systems has become essential. However, the G.652.D fibre used in operative networks struggles to meet the demands of future optical transmission networks for ultra-high-speed, ultra-large-capacity, and ultra-long-distance transmission[2]. As a result, introducing new optical fibre has become imperative. Thanks to its lower attenuation coefficient and larger effective area, G.654.E fibres boost launch power while reducing nonlinear effect, dramatically improving optical signal-to-noise ratio (OSNR), extending unrepeatered transmission distance, and slashing the need for communication repeaters. This translates to cost savings in deployment and maintenance, paving the way for large-scale 400G transmission systems and future Tbit-scale systems development[3].

Currently, G.654.E fibre has been deeply integrated into global communication networks, playing a critical role in the backbone network upgrade projects undertaken by major Chinese operators, including China United Network Communications Group Co., Ltd. (China Unicom), China Mobile Communications Group Co., Ltd. (China Mobile), and China Telecom Corporation Limited (China Telecom). Moreover, it has been instrumental in the development of ultra-long-span private communication networks for the State Grid Corporation of China (SGCC). Furthermore, G.654.E fibre has been deployed in the construction of network infrastructure in countries including the Philippines and Brazil. These applications not only facilitate the interconnection and technological integration of global communication networks but also lay a physical foundation for the large-scale deployment of cutting-edge technologies such as 5G, cloud computing, and AI.

In summary, as the cornerstone technology for next-generation optical networks, G.654.E fibre leverages its exceptional low attenuation and large effective area properties to break through performance bottlenecks in ultra-high-speed, ultra-large-capacity, and ultra-long-distance transmission. It provides a comprehensive solution to modern communication challenges, including soaring bandwidth demands and long-distance transmission constraints. By reshaping network architectures with its technological edge, it plays a strategically vital role in accelerating digital economy growth and fostering global information resource sharing.

Chapter 2 G.654.E Standards

In 2016, Chinese operators became the pioneer in the world to deploy G.654.E fibre in ultra-high-speed terrestrial communications, launching a terrestrial test network project for G.654.E fibre and cable. This initiative thoroughly validated the transmission performance and environmental adaptability of the new optical fibre, establishing a solid foundation for the standardization and industrialization of G.654.E fibre.

In July 2013, the International Telecommunication Union's Study Group 15 (ITU-T SG15) officially initiated discussions on the new G.654 fibre. Between 2014 and 2016, numerous optical fibre companies and operators submitted documents to support the development of G.654.E specifications. In November 2016, ITU-T SG15 officially completed and published the revised version of the ITU-T G.654 standard, titled Characteristics of a Cut-off Shifted Single-Mode Optical Fibre and Cable. This revision introduced the new subcategory G.654.E to support digital coherent transmission systems operating at 100 Gbit/s and beyond in terrestrial transmission network deployment. The updated standard defines key performance indicators for optical fibre, including mode field diameter, attenuation coefficient, and macro-bending loss. In 2020, ITU-T SG15 released a new revision that introduced minor adjustments, including annotations to the cutoff wavelength, to better support the application of the DWDM system specified in the ITU-T G.698.2 standard. In 2024, the ITU-T G.654 standard was further revised, providing additional clarifications regarding the cutoff wavelength[4].

In 2018, the International Electrotechnical Commission (IEC) revised and published the single-mode fibre standard, IEC 60793-2-50, introducing the new subcategory B-654.E (corresponding to ITU-T G.654.E). During the same period in 2018, the Chinese communication industry standard, Characteristics of Cut-Off Wavelength Shifted Single-Mode Optical Fibre (YD/T 3348)[5], was issued. This standard further updated and refined relevant content and performance indicators from the international standard to better align with the actual needs in China.

In 2020, the Chinese national standard, Single-mode Optical Fibres for Telecommunication—Part 2: Characteristics of a Cut-Off Wavelength Shifted Single-Mode Optical Fibre (GB/T 9771.2)[6], was revised, introducing the new subcategory B1.2e (corresponding to ITU-T G.654.E).

In 2022, the Chinese Society for Electrical Engineering formulated and issued the group standard, Technical Specifications for G.654.E optical fiber of electric communication network (T/CSEE 0317)[7]. This standard addresses the needs of electric communication transmission, providing reference and technical support for ultra-long-distance power transmission.

Table 2-1 outlines the technical requirements for G.654.E fibre as specified in ITU-T G.654.E, GB/T 9771.2, YD/T 3348, and T/CSEE 0317.

Table 2-1 Technical Requirements of International and Chinese Standards for G.654.E Fibre

Item	ITU-T G.654.E	GB/T 9771.2	YD/T 3348	T/CSEE 0317
Geometrical characteristics				
Cladding diameter (μm)	125±1	125±1	125±1	125±1
Core concentricity error (μm)	≤0.8	≤0.8	≤0.8	≤0.8
Cladding non-circularity (%)	≤2.0	≤2.0	≤2.0	≤2.0
Coating diameter (uncolored) (μm)	/	235~255	235~255	235~255
Coating diameter (colored) (μm)	/	235~265	235~265	235~265
Coating/cladding concentricity error (μm)	/	≤12.5	≤12.5	≤12.5
Transmission characteristics				
Mode field diameter at 1,550 nm (μm)	(11.5~12.5)±0.7	(11.5~12.5)±0.7	(11.5~12.5)±0.5	12.5±0.5
Effective area at 1,550 nm (μm^2)	/	/	/	125±10
Attenuation coefficient (after cabling) at 1,550 nm (dB/km)	≤0.23	≤0.23	≤0.21	≤0.169
Attenuation coefficient (after cabling) at 1,625 nm (dB/km)	TBD	≤0.40	≤0.40	≤0.21
Attenuation point discontinuity (at 1,550 nm) (dB/km)	/	≤0.1	≤0.1	≤0.1
Attenuation wavelength characteristics at (1,525 nm~1,575 nm) -1,550 nm) (dB/km)	/	≤0.03	≤0.03	≤0.03
Attenuation uniformity (at 1,550 nm) (dB/km)	/	≤0.05	≤0.05	≤0.05
Dispersion coefficient at 1,550 nm (ps/ (nm·km))	17~23	17~23	17~23	17~23
Dispersion slope at 1,550 nm (ps/ (nm^2·km))	0.050~0.070	0.050~0.070	0.050~0.070	0.050~0.070
PMD coefficient (M=20, Q=0.01%) (ps/$\sqrt{km}$)	≤0.20	≤0.20	≤0.20	≤0.20
Cable cutoff wavelength (nm)	≤1530	≤1530	≤1530	≤1520
Macrobending loss at 1,625 nm (30mm radius and 100 turns) (dB)	≤0.1	≤0.1	≤0.1	≤0.05
Mechanical performance				
Proof test level (GPa)	≥0.69	≥0.69	≥0.69	≥0.69
Tensile strength at the Weibull probability level of 15% (0.5m nominal length) (GPa)	/	≥3.14	≥3.14	≥3.14
Tensile strength at the Weibull probability level of 50% (0.5m nominal length) (GPa)	/	≥3.80	≥3.80	≥3.80
Curl radius (m)	/	≥4	≥4	≥4
Coating strip force (average) (N)	/	1.0~5.0	1.0~5.0	1.0~5.0
Coating strip force (peak value) (N)	/	1.0~8.9	1.0~8.9	1.0~8.9
Dynamic fatigue parameter (Nd)	/	≥20	≥20	≥20
Environmental performance				
Steady damp heat (at 1,550 nm and 1,625 nm) (dB/km)	/	≤0.05	≤0.05	≤0.05
Dry heat (at 1,550 nm and 1,625 nm) (dB/km)	/	≤0.05	≤0.05	≤0.05
Temperature characteristics (at 1,550 nm and 1,625 nm) (dB/km)	/	≤0.05	≤0.05	≤0.05
Water immersion (at 1,550 nm and 1,625 nm) (dB/km)	/	≤0.05	≤0.05	≤0.05

Chapter 3 Application Research on G.654.E Fibre

The industry chain has been consistently focused on the core optical transmission capabilities, driving research on the applied technology and industrial advancements based on G.654.E fibre to build cutting-edge ultra-high-speed transmission infrastructures.

3.1 Research on 800G Ultra-High-Speed Applications Based on G.654.E Fibre

The optical communication system based on erbium doped fibre amplifier (EDFA) and G.652.D fibre cannot keep pace with the development demands of large-capacity, long-distance systems beyond 400G. To address this challenge, it is essential to explore the integration of key technologies such as G.654.E fibre, Raman amplifiers, high-speed optical devices, and higher-order modulation. The requirements for 800G/Tbit transmission, along with network upgrades, give an opportunity for the introduction of new fibre infrastructure. Moreover, pioneering research on 800G high-speed transmission interconnections based on G.654.E fibre has yielded numerous breakthrough results.

In March 2021, China Mobile achieved the first single-carrier 800G transmission over a distance exceeding 1,000 km in China[8]. The test results demonstrated that the integration of new coding technology, hybrid amplification techniques, and G.654.E fibre can significantly enhance the long-distance transmission capacity for 800G. This breakthrough lays a foundation for operators to scale up the commercialization of 800G technology.

In July 2022, China Mobile again set a new record by achieving a groundbreaking single-carrier 800G transmission over a distance of 2,018 km based on G.654.E fibre[9]. This achievement marks a significant milestone in the deployment of next-generation ultra-high-speed information networks.

In May 2024, China Unicom achieved a single-carrier 800G PCS-16QAM transmission over a distance of 3,000 km based on G.654.E fibre[10].

In July 2024, China Unicom comprehensively verified the performance indicators of the 800G solution in the C+L band based on G.654.E fibre in accordance with the standard span loss requirements for actual projects. The solution achieved single-fibre 64T transmission over a distance exceeding 1,000 km, representing a significant improvement compared with G.652.D fibre, and another breakthrough in the development of 800G ultra-high-speed optical transmission technology. This achievement provides a robust decision foundation regarding metropolitan area network (MAN) transmission and the construction of high-speed interconnection links for smart computing centers[11-12].

3.2 Research on Large-capacity Applications of S-band Expansion Based on G.654.E Fibre

In April 2024, China Telecom completed a multi-band large-capacity transmission experiment in the S-, C-, and L-bands based on G.654.E fibre. This experiment achieved the maximum real-time single-wavelength rate of 1.2 Tbit/s, with the transmission capacity exceeding 120 Tbit/s on a single optical fibre[13]. Besides the traditional C-band, the system's spectral width is now extended to the S- and L-bands, achieving an ultra-wide communication bandwidth of up to 17 THz across the S-, C-, and L-bands, covering wavelengths from 1,483 nm to 1,627 nm.

In September 2024, China Mobile conducted a single-carrier 1Tbit/s S6.8T+C6T+L6T wide-spectrum transmission experiment based on G.654.E fibre, achieving an ultra-large transmission capacity of 214T on a single optical fibre[14].

These groundbreaking achievements set up milestones in the development of 800G and Tbit/s ultra-high-speed optical transmission technology, establishing a solid experimental foundation for the future evolution and upgrade of extended bands in transmission networks.

3.3 Research on the Application of Ultra-Long-Span Unrepeatered Transmission Based on G.654.E Fibre

In the context of ultra-long-span unrepeatered transmission applications for electric power, SGCC has conducted a series of laboratory transmission tests. In 2018, single-span unrepeatered transmission over 713.2 km for 2.5G and 665.7 km for 10G were achieved based on G.654.E fibre, setting new world records for single-span unrepeatered optical transmission at 2.5G and 10G[15], as illustrated in Fig. 3-1. In 2019, again based on G.654.E fibre, the single-span unrepeatered transmission distances reached 670.64 km for 50G, 653.35 km for 100G, 601.93 km for 200G, and 502.13 km for 400G, once more setting world records for single-span unrepeatered optical transmission at 50G, 100G, 200G, and 400G[16], as illustrated in Fig. 3-2.

Fig. 3-1 Single-span Unrepeatered Laboratory Transmission Test Results for 2.5G and 10G Systems[15]

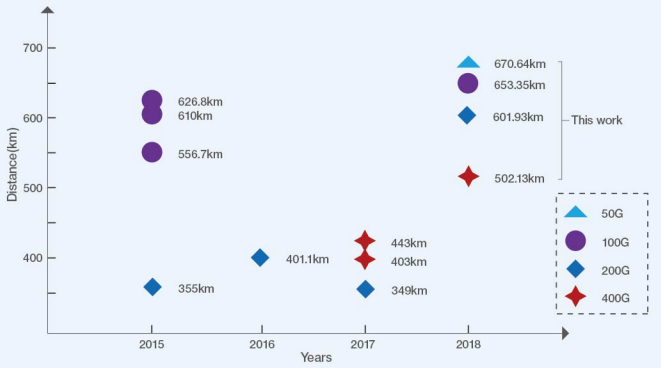

Fig. 3-2 Single-span Unrepeatered Laboratory Transmission Distance[16]

To further extend the unrepeatered transmission distance, distributed Raman amplifiers are commonly utilized in terrestrial long-distance transmission systems to assist EDFAs in generating signal gain, thereby improving the system's OSNR. In 2019, Reference [17] presented an in-depth study on the application of G.654.E fibre in distributed Raman amplification systems.

3.4 Research on the Application of G.654.E Fibre in Sensing

Approximately 70% of the repeater sections in the primary backbone power communication network exceed 200 km in length. However, traditional distributed fibre sensing technologies cannot provide comprehensive single-end measurement coverage, resulting in a lack of real-time, efficient, and no blind spot monitoring for operational parameters of OPGW cables, such as stress, vibration, attenuation, and temperature. To address the limitations in single-end monitoring distances, the application of G.654.E fibre in Brillouin optical time domain reflectometer (BOTDR) sensing systems has garnered significant attention as a solution to extend sensing distances.

In 2023, SGCC achieved a sensing distance of 253 km using a remote optically pumped amplifier (ROPA) and reverse Raman amplification techniques, based on G.654.E fibre. This setup provided a spatial resolution of 40m, effectively improving the sensing distance of the BOTDR system[18], as illustrated in Fig. 3-3.

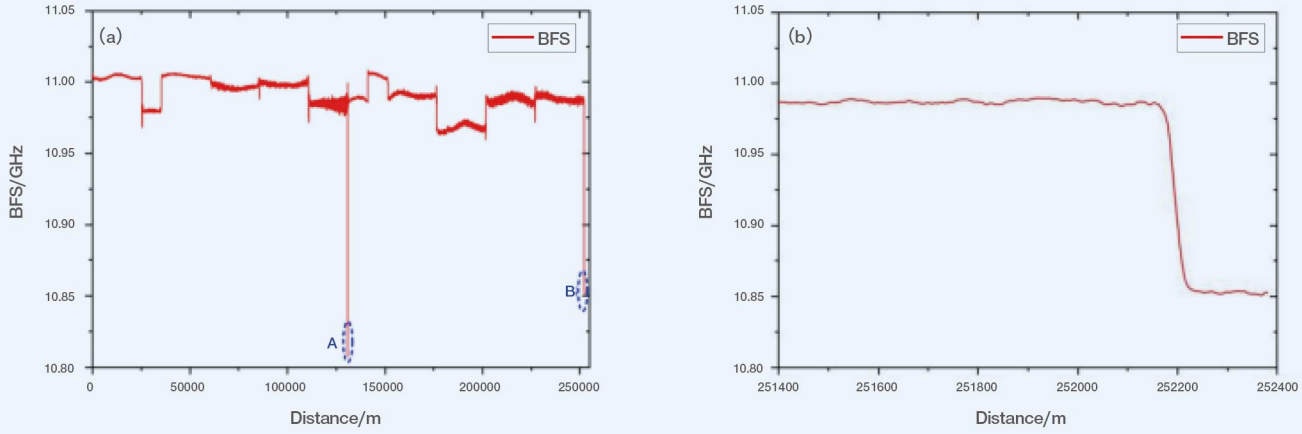

Fig. 3-3 Sensing Distance Test Results Based on G.654.E Fibre[18]

The ultra-low loss characteristics of G.654.E fibre enable extended transmission distances for detecting light, while its large effective area reduces the nonlinear threshold of the optical fibre and increases the optical power of the injected pulse, thereby effectively extending detection distance of BOTDR. Experimental results indicate that the BOTDR sensing system based on G.654.E fibre excels in both measurement accuracy and spatial resolution. This showcases the potential of G.654.E fibre technology in the sensing field with new possibilities for the development of long-distance sensing systems. Moreover, this system can monitor the temperature and strain of electric optical cables effectively, and quickly locate the breakpoint in the event of an optical cable interruption, thereby ensuring the safe operation of the power grid. This achievement is anticipated to have significant implications in various fields, including communications and geological exploration.

3.5 Research on the Application of G.654.E Fibre in Quantum Communication

Harnessing the fundamental principles of quantum mechanics, Quantum Key Distribution (QKD) enables secure key distribution between users, achieving the highest level of communication security when paired with “one-time pad” (OTP) encryption method. However, the QKD’s range is limited by factors such as the inherent loss of communication fibre and detector noise.

To achieve QKD over extremely long distances, the University of Science and Technology of China collaborated with Tsinghua University, Jinan Institute of Quantum Technology, and Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS). By developing technologies such as low-crosstalk phase reference signal control and ultra-low-noise single-photon detectors, and utilizing G.654.E fibre, they successfully achieved point-to-point long-distance QKD over 1,002 km with optical fibre[19-21] (as illustrated in Fig. 3-4 and Fig. 3-5). This achievement not only sets a world record for unrepeatered QKD distance with optical fibre but also provides a solution for high-speed backbone links in intercity quantum communication. The findings have been published in the Physical Review Letters, representing “an extremely important advancement in this field and a new milestone in QKD technology”.

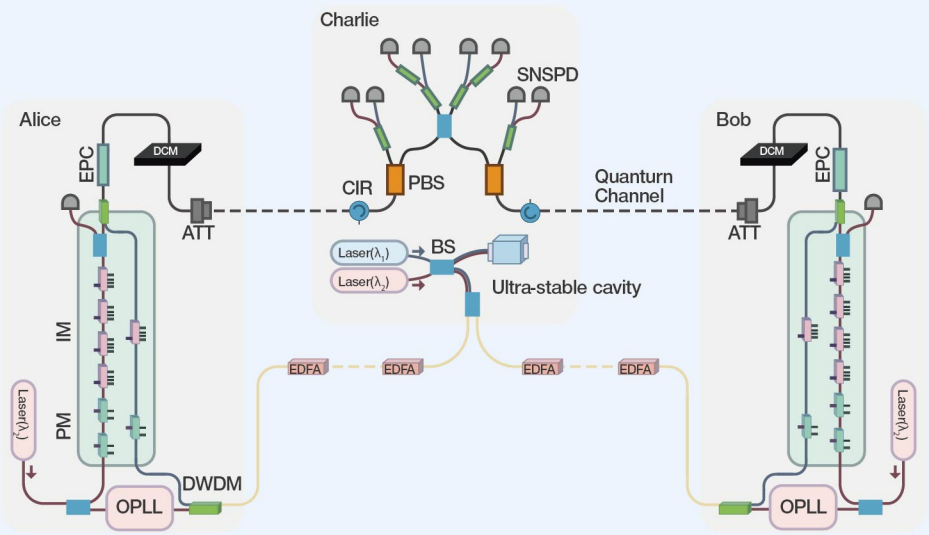

Fig. 3-4 Schematic Diagram of the Experimental System[20]

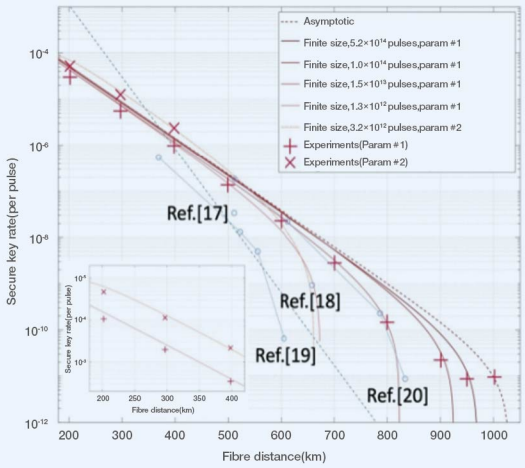

Fig.3-5 Experimental Secure Key Rate Results[20]

Chapter 4 Engineering Application Cases of G.654.E Fibre

G.654.E fibre has been successfully used in numerous national network infrastructure projects undertaken by China Mobile, China Telecom, China Unicom, and SGCC, as well as those in the Philippines, Brazil, and various other countries.

4.1 Engineering Application Cases of China Unicom

From 2015 to 2017, China Unicom conducted pilot projects in both the eastern and the western trunk networks. Specifically, the Jinan-Qingdao section in Shandong was selected as the eastern test network, featuring approximately 430 km of optical cable installed in conduits. This section was used to perform an existing network-based transmission test for 400G. The Hami-Barkol section in Xinjiang served as the western test network, featuring around 150 km of optical cable installed overhead. This test section operated in a complex environment, traversing the Gobi Desert, the Mount Tianshan, and the grasslands, with the actual operating temperature of the optical cable ranging from -30°C to 60°C, and the wind force reaching up to scale 12. These conditions allowed for a thorough evaluation of the effects of overhead installation of G.654.E fibre, as well as the long-term operational performance of the optical cable in harsh environments[22-24]. The test thoroughly validated the effect of the new G.654.E fibre on improving the transmission performance of 400G systems. Such China Unicom's projects of the new optical fibre have pioneered the actual terrestrial deployment and applications of G.654.E fibre.

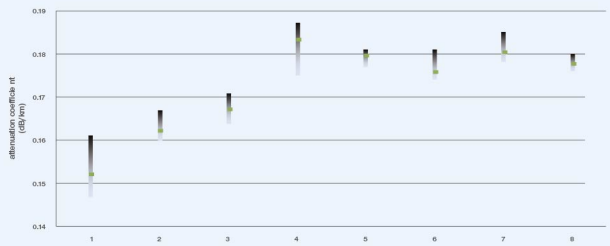

Fig. 4-1 Fibre Attenuation[23]

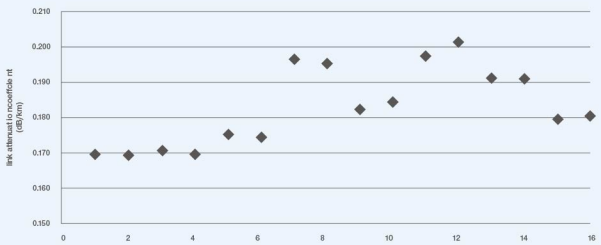

Fig. 4-2 Optical Cable Attenuation

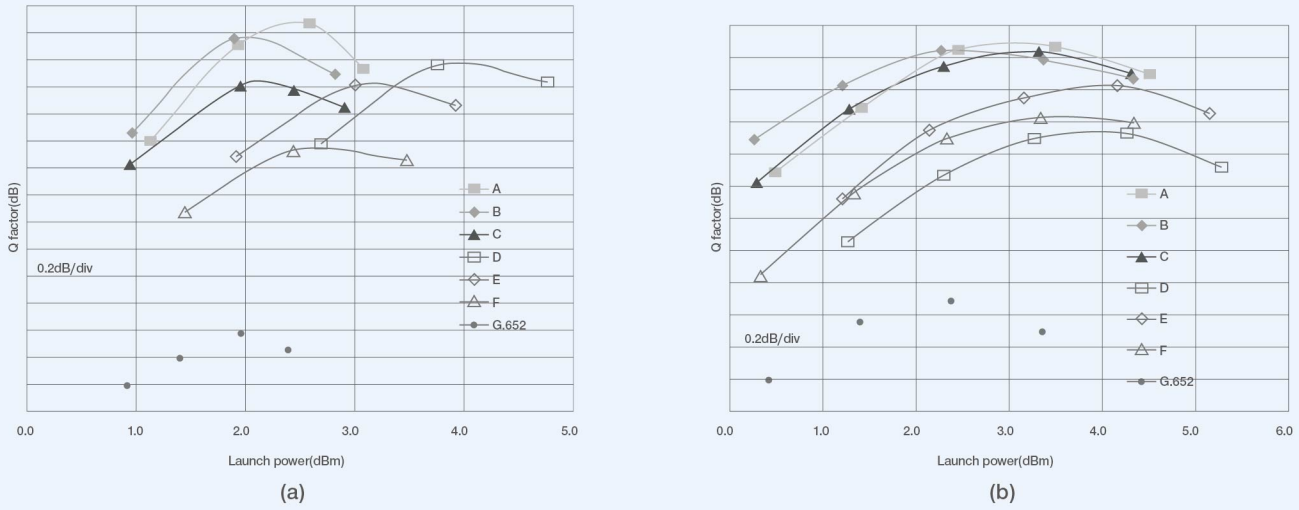

Fig. 4-3 Q Factor vs Launch Power at the Receiver Side of the System[23] (a) System Supplier A; (b) System Supplier B

4.2 Engineering Application Cases of China Mobile

In 2016, China Mobile deployed the Beijing-Tianjin-Jining terrestrial trunk cable with a G.654.E+G.652.D Hybrid Fibre Cable (HFC) structure, spanning a total length of 1539.6 km. The trial commercial testing focused on validating the key performance indicators of the G.654.E and G.652.D fibre cables installed in the existing network, such as link loss, optical cable loss, and splicing loss. Additionally, it validated the performance of 100G, 200G, and 400G hybrid transmission systems in multi-span configurations using two types of optical fibres. The test results indicated that the G.654.E cable demonstrated an average loss improvement of 0.02 dB/km compared with G.652.D cables, which lives up to expectations. When supporting 100G, 200G, and 400G systems, the G.654.E cable exhibited improvements in all core transmission performance indicators. Under the span-based configuration of G.654.E cable in the existing network while ensuring standard margins, the following results were achieved for the first time: single-carrier 400G 16QAM transmission over a distance exceeding 600 km, single-carrier 200G 16QAM coded transmission exceeding 1,000 km, and 200G QPSK coded transmission exceeding 1,500 km. These achievements signify that G.654.E fibre has achieved commercial viability[25-27]. China Mobile has successfully validated the reliability of single-carrier 400G transmission, as well as other transmission technologies exceeding 100G over G.654.E fibre for the first time, laying a foundation for the evolution of backbone transmission networks towards large-capacity and high-speed.

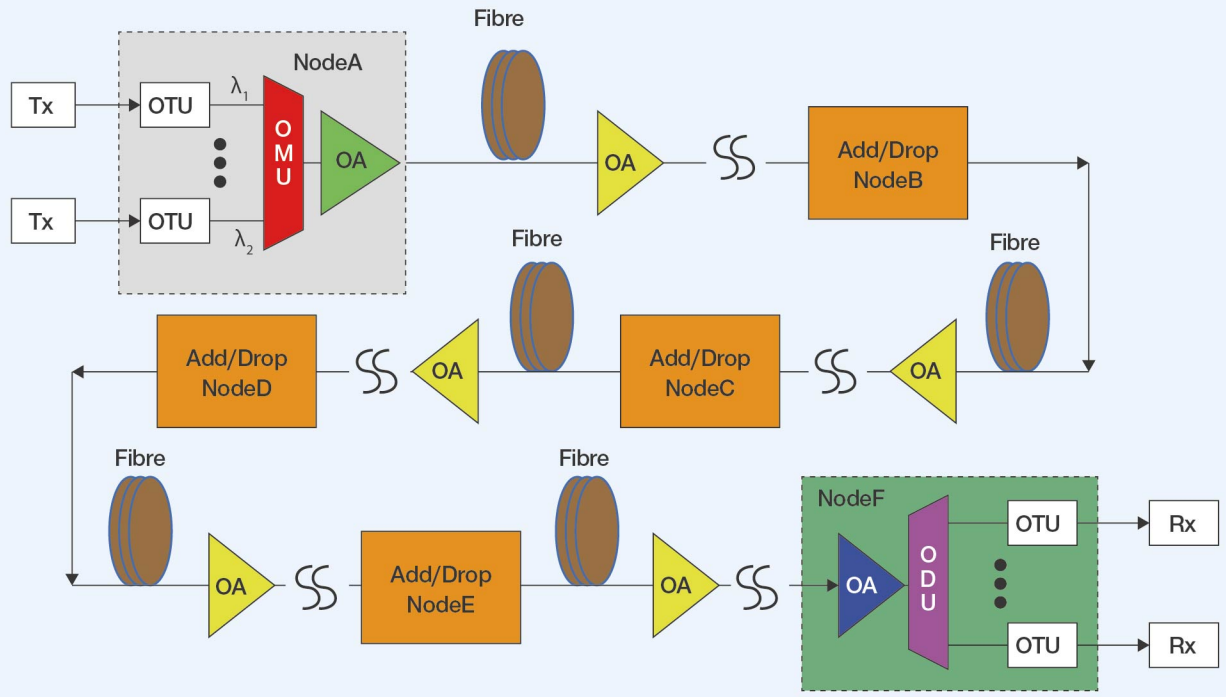

Fig. 4-4 Schematic Diagram of Existing Network-based Test Setup[26]

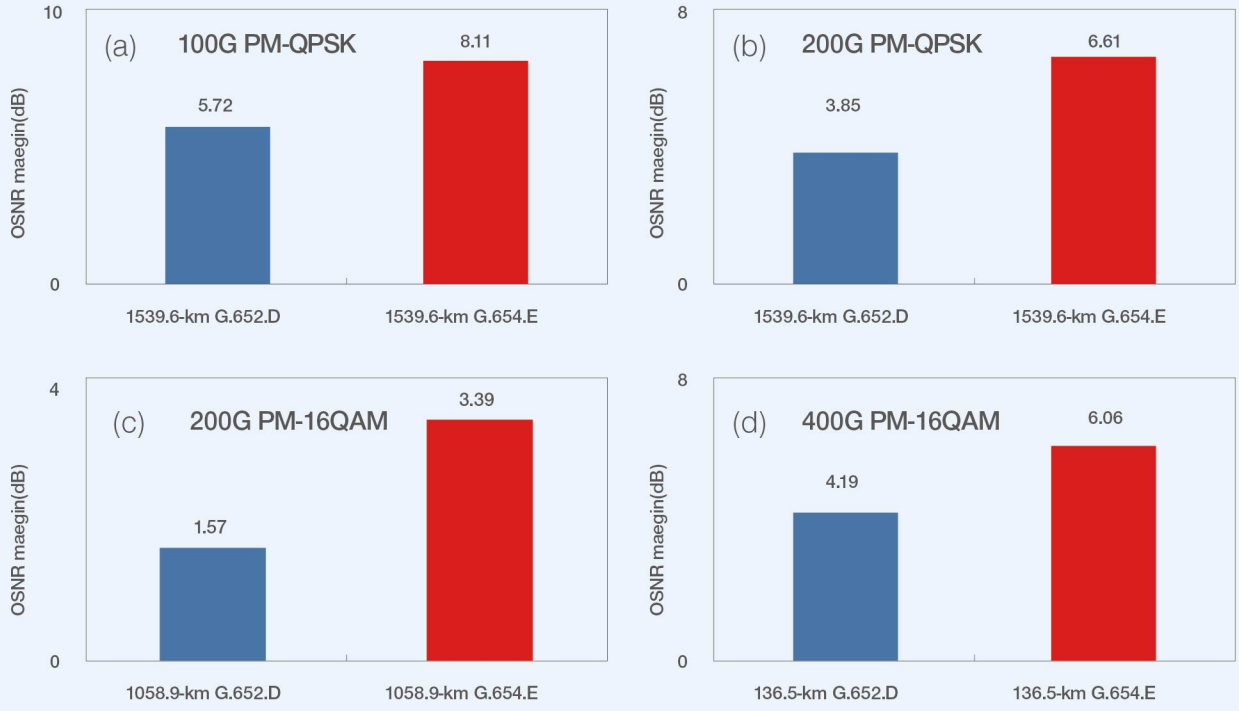

Fig. 4-5 Comparison of System OSNR Margins in G.654.E Fibre and G.652.D Fibre[27]

4.3 Engineering Application Cases of China Telecom

In 2019, China Telecom constructed China's first G.654.E terrestrial trunk cable, spanning 1,970 kilometers between Shanghai and Guangzhou[28]. The company's consistent verification of technical indicators, construction techniques, construction schemes, and acceptance specifications have resulted in well-defined technical parameters, including mode field diameter (MFD), effective area, and attenuation index, guiding optical fibre and cable manufacturers to invest in R&D and achieve large-scale production.

During the engineering phase of existing network projects, discrepancies in fibre profiles, production process, and material compositions of G.654.E fibre among different optical fibre manufacturers, combined with incompatibilities between optical fibre splicing equipment and the new optical fibre, have imposed adverse impacts on existing network applications. In response to this, China Telecom took the initiative in 2021 to coordinate the collaboration among various stakeholders across the entire industry chain, including design institutes, construction organizations, optical cable manufacturers, and test device providers. This collaborative effort involved developing and testing a universal splicing mode for the new G.654.E fibre, ensuring the compatibility among multiple manufacturers. Simultaneously, the initiative advanced the development and application of a three-wavelength OTDR to comprehensively assess the performance of G.654.E fibre. These efforts have provided technical support to promote the deployment, operation, and maintenance of G.654.E fibre in existing networks[29].

Leveraging the newly constructed G.654.E fibre line, China Telecom has completed China's first existing network test of commercial equipment for 400Gb/s ultra-long-distance WDM transmission, achieving unrepeatered transmission over a distance exceeding 1,900 km. The existing network test demonstrated full-range unrepeatered transmission between Shanghai and Guangzhou over G.654.E fibre at 100G, 200G, and 400G transmission rates, with no error codes recorded during more than 12 hours of continuous operation. Additionally, the system operated stably throughout the testing period. Calculations indicate that PM-16QAM 400Gb/s unrepeatered transmission is feasible over approximately 1,500 km, provided standard OSNR margin requirements can be met. Existing network comparison testing results show that the application of G.654.E fibre improves the system's OSNR by 3.5 dB compared with G.652.D fibre. This improvement results in practical benefits, such as reductions in the number of repeaters and energy consumption, thereby providing strong support for the development of transmission systems with single-wavelength rates of 1T and beyond[29]. Through existing network projects, China Telecom has gained extensive experience in construction, operation, and maintenance, promoting the maturation of the G.654.E industry chain. This effort has established a solid foundation for the large-scale deployment of G.654.E fibre in existing networks and the development of the industry chain.

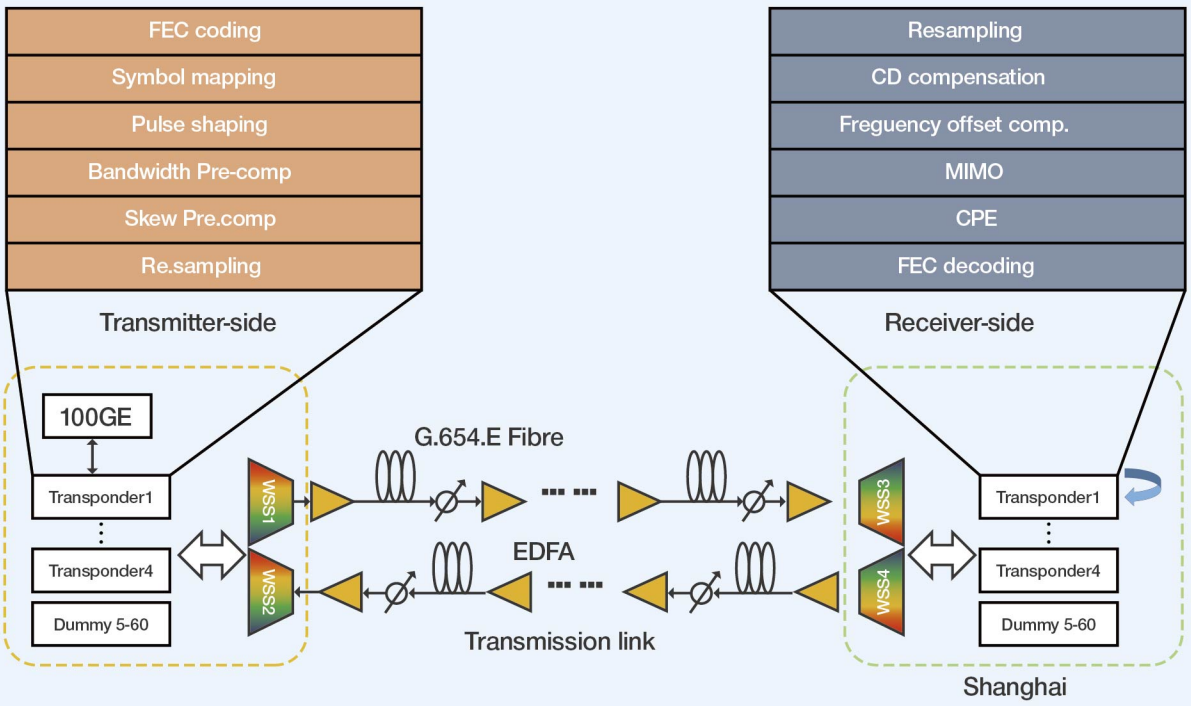

Fig. 4-6 Transmission System Layout[28]

4.4 Engineering Application Cases of SGCC

In recent years, SGCC has actively explored the application of new optical fibres featuring lower attenuation coefficient and larger effective area. In 2020, the Yazhong-Jiangxi ±800kV UHVDC Transmission Project and the Northern Shaanxi-Hubei ±800kV UHVDC Transmission Project pioneered the use of G.654.E fibre as an effective solution for ultra-long-station-distance transmission in UHV projects, achieving a breakthrough in long-distance, unrepeatered transmission with a single span of 467 km[30-33], as illustrated in Fig. 4-7.

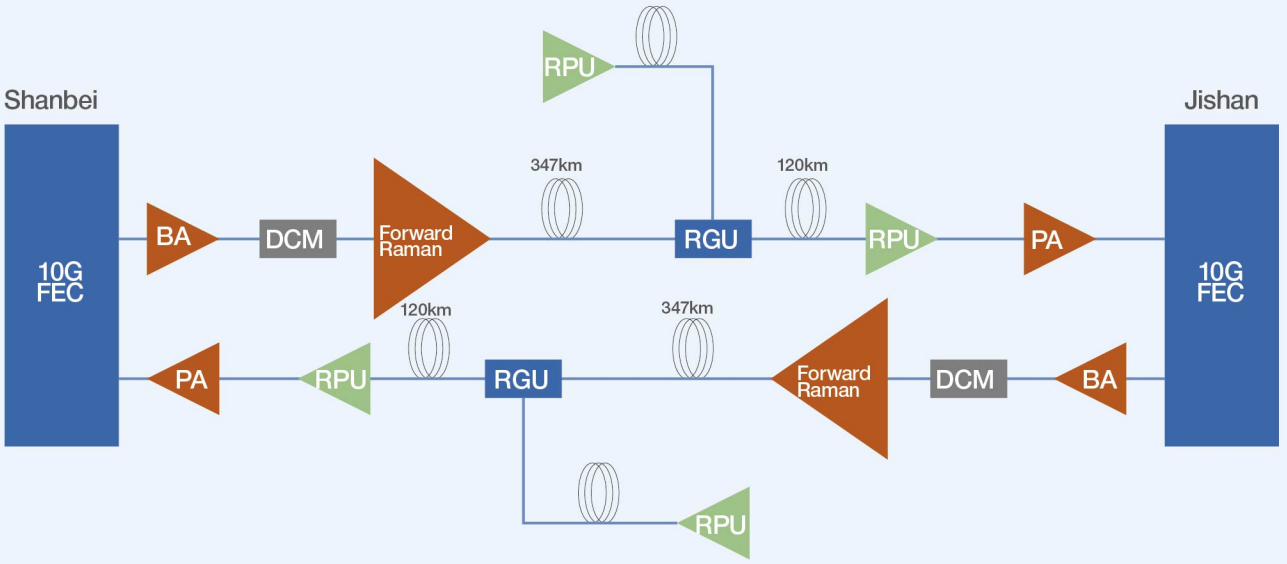

Fig. 4-7 Transmission System Layout[33]

Thanks to the use of G.654.E fibre, these two UHV projects have set new records for terrestrial unrepeatered transmission distances in power communication, both domestically and internationally. They have established themselves as the international leading examples with the longest single span (467 km) and the largest capacity in the field, marking the dawn of a new era in power communication network applications. They also show significant reference value for the power energy industry by leveraging communication technology to drive the transformation and upgrade of new power systems, support the implementation of "carbon peaking and carbon neutrality" goals, and advance energy transformation and green development.

To sum up, the application cases of G.654.E fibre in various operators' long-distance backbone networks and SGCC's UHVDC transmission projects have fully demonstrated its technical advantages in high-speed, long-distance, and large-capacity communications. This success has established a solid foundation for promoting the large-scale deployment of G.654.E fibre in existing networks and the healthy development of the industry chain.

Chapter 5 Prospects

As a high-performance optical fibre, G.654.E fibre possesses broad development prospects across technology, applications, and market.

5.1 Technical Prospects

Continuous improvement of product performance

01

Currently, the attenuation coefficient of G.654.E fibre is already low. With continuous improvements in manufacturing processes and evolution of communication technology towards higher speeds and longer transmission distances, the attenuation coefficient of G.654.E fibre is expected to decrease further, enabling even longer transmission distances. Additionally, the attenuation spectra of the C- and L-bands become flatter with the application of band extensions, reducing attenuation in the wavelength range of 1,612~1,625 nm.

Support for higher transmission speeds

02

Advancements in 5G, AI, cloud computing, and global interconnection are driving increasingly stringent requirements for higher fibre transmission speeds. With its outstanding performance, G.654.E fibre is poised to become the preferred choice for supporting future Tbit/s ultra-high-speed transmission technologies.

Integration with other technologies

03

G.654.E fibre may be integrated with other emerging technologies (e.g., multi-core fibre and hollow-core fibre) to create more efficient transmission solutions tailored to meet the requirements of various application scenarios.

5.2 Application Prospects

Scenarios including long- and ultra-long-distance transmission in backbone networks, metro data center interconnection (DCI), and metro/regional core interconnection are experiencing a new wave of upgrades. As a result, ultra-high-speed optical communication transmission technology based on G.654.E fibre has become a focus area within the industry.

01

Long- and ultra-long-distance transmission in backbone networks

G.654.E fibre features significant advantages in long-distance, large-capacity backbone networks, effectively supporting transmission rates of 400G and beyond.

02

Metropolitan area network (MAN) and data center interconnection

As data centers continue to expand in scale and data traffic surges exponentially, G.654.E fibre is well-positioned to meet the demands for high-speed, stable data transmission over short and medium distances between MANs and data centers, thereby bolstering the network infrastructure of intelligent computing centers.

03

Ultra-long-span transmission in power communication

The long single span is a notable feature of power communication networks, setting them apart from operators' communication networks, especially for radio relay transmissions exceeding 300 km. This imposes more stringent requirements on the performance of optical fibres. G.654.E fibre can support ultra-long-distance, high-reliability, and low-latency communication. According to the *Guiding Opinions on the Rolling Planning of Communication Networks during the 14th Five-year Plan Period* issued by the National Electric Power Dispatching and Control Center, G.654.E fibre should be prioritized for communication relay sections exceeding 300 km. With a new round of construction peak for UHV projects on the horizon, the demand for G.654.E fibre is expected to experience explosive growth, promising vast application prospects in the power communication industry.

Integrated sensing and communication (ISAC) application

04

The ultra-low loss characteristic of G.654.E fibre enables longer transmission distances for probe light, while its large effective area reduces the nonlinear threshold of the optical fibre and increases the optical power of the injected pulse, thereby effectively extending the monitoring distance of the sensor system. The use of G.654.E fibre enables effective long-distance monitoring, facilitating the implementation of ISAC on optical fibre.

Unrepeatered quantum communication application

05

The distance of QKD is limited by factors such as the inherent loss of communication fibre and detector noise. G.654.E fibre is poised to extend the unrepeatered distance of quantum communication, enhancing communication security to a higher level.

5.3 Market Prospects

Since 2019, the three major Chinese operators have progressively increased their centralized procurement volume of G.654.E fibre. Below is a detailed analysis:

In 2019, China Telecom completed its first centralized procurement of G.654.E cable, totaling 293,100 core kilometers. In 2022, China Telecom completed the 2022 centralized procurement of optical cables (the first batch) for the trunk cable construction project, including a bid package of 607,000 core kilometers of G.654.E trunk cable. In 2023, China Telecom completed the 2023 procurement project for optical cables and supporting components for the trunk cable construction project, including a bid package of 242,000 core kilometers of G.654.E trunk cable. In 2024, China Telecom completed the 2024 procurement project for optical cables and supporting components for the trunk cable construction project, including a bid package of 823,100 core kilometers of G.654.E trunk cable. To date, China Telecom has deployed a total of 2.2 million core kilometers of G.654.E fibre.

In 2019, China Unicom initiated the 2018-2019 centralized procurement project for trunk cables (G.654.E), totaling approximately 2,971 cable kilometers. In 2024, G.654.E fibre emerged as the dominant choice for trunk cables in China Unicom' centralized procurement of optical cables, totaling up to 3 million core kilometers.

In 2022, China Mobile launched the centralized procurement of G.654.E cable, totaling approximately 2,134 cable kilometers (over 332,400 core kilometers). In 2023, China Mobile conducted the 2023-2024 centralized procurement project for G.654.E fibre and cable, totaling 1,227,900 core kilometers.

In addition to the centralized procurement projects of these major operators, their provincial branches have also made multiple procurements.

In 2024, China State Railway Group Co., Ltd. initiated the procurement of G.654.E products[34].

Over the past five years, SGCC has deployed more than 10,000 cable kilometers of G.654.E OPGW and has clearly specified the use of ultra-low-loss G.654.E fibre in several ongoing and planned UHV projects. Currently, G.654.E fibre has been applied in batches in six UHV projects, including the Hami-Chongqing Project and the project from the upper reaches of the Jinsha River to Hubei Province (as detailed in Table 5-1).

Project/Application	Year	Organization
Middle Yazhong River-Jiangxi UHVDC Transmission Project	2020	SGCC
Northern Shaanxi-Hubei UHVDC Transmission Project	2021	SGCC
Upper Jinsha River-Hubei UHVDC Transmission Project	2023	SGCC
Eastern Gansu-Shandong UHVDC Transmission Project	2023	SGCC
Hami-Chongqing UHVDC Transmission Project	2023	SGCC
Northern Shaanxi-Anhui UHVDC Transmission Project	2024	SGCC

Table 5-1 SGCC's UHV Projects Utilizing G.654.E Fibre in the Past Five Years

Several countries worldwide have drawn on China's project experience and technical standards related to the use of G.654.E fibre in UHV projects to develop their own standards for power communication design and construction, , which have already been put into engineering applications.

The global market for G.654.E fibre is demonstrating a steady growth trajectory. It is estimated that by 2030, the market size will reach USD 3 billion, with a compound annual growth rate (CAGR) of 9.1% from 2024 to 2030.

As 5G and other emerging technologies continue to expand, coupled with the growing demand for computing power and the rapid development of AI large model applications, the need for high-performance optical fibre is set to increase. G.654.E fibre has emerged as a mainstream choice in the industry by virtue of its large effective area, low loss, and low nonlinear coefficient. As the application scenarios for G.654.E fibre continue to expand, its market share is expected to rise continuously.

In summary, G.654.E fibre, with its exceptional technical performance and extensive application potential, is poised to play a pivotal role in future communication networks and presents broad market prospects.

Chapter 6 Summary

As a vital cornerstone of the network, optical fibre and cable technology is advancing rapidly in the context of the ongoing evolution and upgrade of optical transmission networks. Driven by market and technological factors, G.654.E fibre has emerged as a solution.

G.654.E fibre is a high-performance optical fibre boasting a lower attenuation coefficient and a larger effective area. The combination of these two features enhances optical power during signal transmission, reduces non-linear effect, effectively extends transmission distances, cuts down on the number of relay stations, optimizes overall system performance, and ultimately lowers the construction, operation, maintenance costs of communication networks.

Through collaborative innovation and close cooperation across the industry chain, substantial breakthroughs have been achieved in the application research and exploration of G.654.E fibre. This fibre not only showcases leading capabilities in optical fibre communication technology but also stands out as the preferred choice for 400G, 800G, and future Tbit/s ultra-high-speed transmission technologies. Its broad application prospects span across various fields, including long- and ultra-long-distance transmission in backbone networks, MAN and data center interconnection, ultra-long-span unrepeatered power communication transmission, ISAC, and quantum communication. It will significantly accelerate the commercialization of new optical fibre technologies and drive the upgrade of network infrastructure.

G.654.E fibre enables longer transmission distances, larger system capacity, extended spans, and increased system margins, delivering substantial value to long-distance transmission networks. Engineering application cases from China Unicom, China Mobile, China Telecom, and SGCC have fully demonstrated the application value of G.654.E fibre, providing both theoretical and practical foundations for its large-scale deployment and the development of next-generation backbone networks. Furthermore, they have contributed to the accumulation of expertise in the construction, operation, and maintenance of G.654.E fibre in existing networks, offering invaluable insights for the development of global optical fibre networks.

G.654.E fibre is gradually transitioning to large-scale commercial use, with increasing procurement volumes for G.654.E fibre and cable both domestically and internationally. The demand for new optical fibre is emerging as a new driver for the development of the optical fibre and cable market, spurring continuous innovation and progress within the industry.

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