Newly structured Hollow-Core Fiber and its open innovation field for Power over fiber, Radio over fiber and ultra-low latency application (Invited talk)

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ABSTRACT

For the next generation network, ultra-low latency network must be use for smart society vehicle. For this purpose, we have built a campus network using hollow-core fiber, aiming for a breakthrough from devices that will meet the ultra-low delay requirements of Beyond 5G. Hollow-core fibers have a air hole in the core and have succeeded in trapping light in the core. Using the characteristics of this fiber, we will report on the current experimental results regarding the possibilities of multi-branch access, ultra-multi-wavelength networks, radio over fiber (RoF), and power over fiber (PWoF). We also opened the Keio Future Optical Network Open Research Center to make these available for open use.

Keywords: Beyond 5G, Low latency, Hollow-core fiber, Optical Network, IOWN, Digital Twin

1. INTRODUCTION

In the 21st century, optical networks have made great progress as a high-speed, wide-band link technology, and computer science services such as cloud services have been enriched. In the next generation Beyond 5G, further development is being encouraged in seven areas in particular [1][2], among which ultra-low latency and energy saving are given high priority. Ultra-low latency services are in high demand for new smart social services such as robot control and autonomous driving. In addition, low latency is important not only in the conventional wireless access section but also in a certain range (we call it area space which is approximately 10 to 20 Km area). On the other hand, low power consumption is also a goal of the sustainable development goals (SDGs), and there are high expectations for optical technology, which can achieve power savings of 1/500 to 1/1,000 compared to electricity. This article describes in detail the status and goals of the research conducted by Keio University's "Keio Future Optical Network Open Research Center"' which has been underway since 2023.

2. Open Research Center

2.1 Keio Future Optical Network Open Research Center

Figure 1 shows the targets of Beyond 5G compiled by the Ministry of Internal Affairs and Communications' Beyond 5G Wired Network Study Group, of which Yamanaka served as the chairperson. Once again, we set out to achieve a major breakthrough in low power and ultra-low latency using optical networks. In order to achieve ultra-low latency, a breakthrough from not only protocol level but also the device level is essential, and at the same time, we would like to aim for a paradigm shift that vertically integrates networks, systems, and even their applications. In that case, a system that collaborates with researchers and engineers, including many application researchers, is essential. Figure 2 shows the Keio Future Optical Network Open Research Center [3], which was created in April 2023 with support from the Ministry of Internal Affairs and Communications (MIC) of Japan. This is a research center that has installed the world's only hollow-core fiber cables on its campus, which will be described in the next chapter, to achieve ultra-low latency not only on the rack or in the floor but also on the multi-building campus. This center is an open laboratory that can be used by researchers from domestic and international companies and universities by sharing their research objectives. We are also aiming to collaborate with open labs in the United States, and are working to create a global consortium [4].

2024 24th International Conference on Transparent Optical Networks (ICTON) | 979-8-3503-7732-3/24/$31.00 ©2024 IEEE | DOI: 10.1109/ICTON62926.2024.10648061

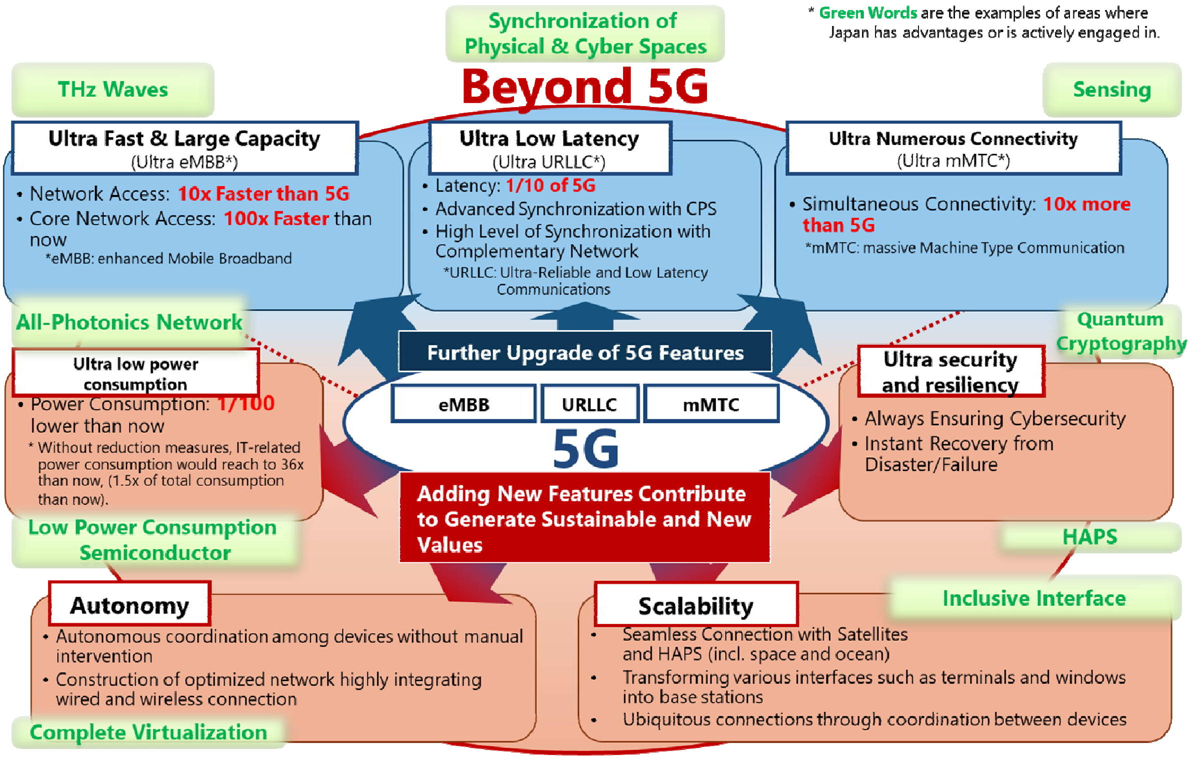

Figure 1. Target for beyond 5G

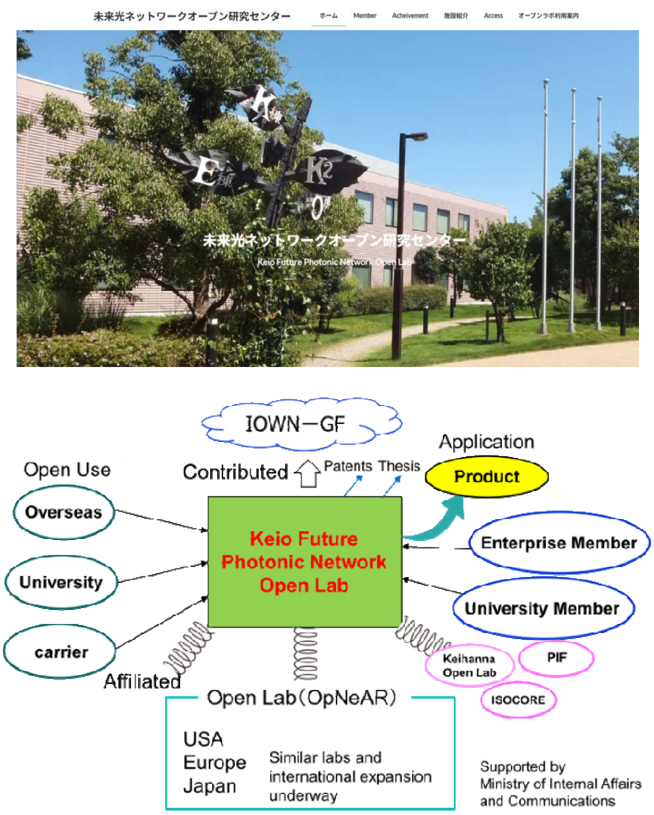

Figure 2. Photo and structure for Keio Future optical network open research center

2.2 Area Space Computing

The structure, principle, and merits of hollow core fiber named Hollow-core fiber will be discussed later, but the goal of a low-latency campus network is to create an extremely low-latency network in a certain area (~20 km) and to synchronize computer and memory resources . This is an application of the development of technology that allows low-latency fixed connections. Figure 3 shows Beyond 5G, which is the aim of this research. In this way, we aim to achieve low latency between or among systems, rather than low latency at points like conventional 5G wireless access. Resources within a certain area are treated as a tightly coupled resource pool without being aware of their location. Therefore, efficiency is high and energy can be reduced. Because unused systema can be power down and scale-out scale-down can be automatically done. Figure 4 shows the spatiotemporal synchronized digital twin that they are aiming for. Synchronize and acquire information between devices dispersed in space for example, Autonomous-driving cars and create a digital twin on cyber. Based on the information on the network, predict the short-term future for example, 30 seconds later in an intersection. If cars collide at a planned future intersection, there is time to simulate whether or not to let one of them go first. This is called a "future-predicting" or "future-ideal" digital twin. We aim to create something that can backwards control the present to create the safest and most efficient future in terms of energy. This is the vision of the Keio Future Optical Network Open Research Center [5][6][7]. In this way, we will consider everything from devices to network technology that makes full use of them, and even computer architecture, and will also collaborate with research on applications such as autonomous driving and real-time control robots. For this reason, Keio University has established an open research center and is recruiting collaborators from an early stage.

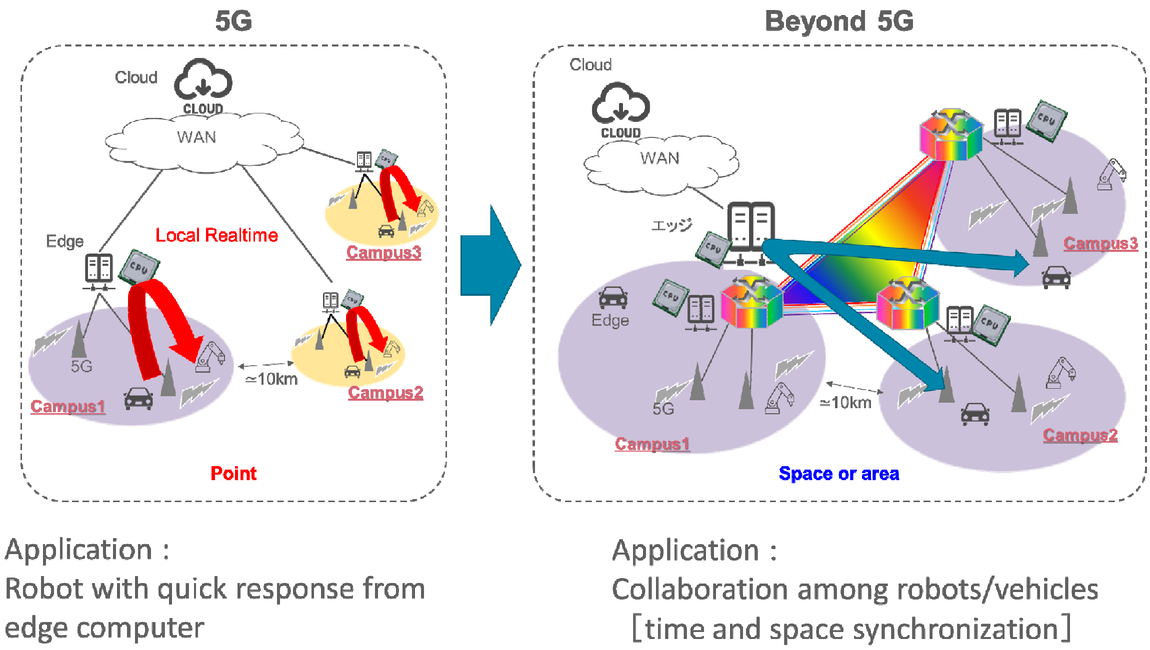

Figure 3. Area space computing having time-space synchronization

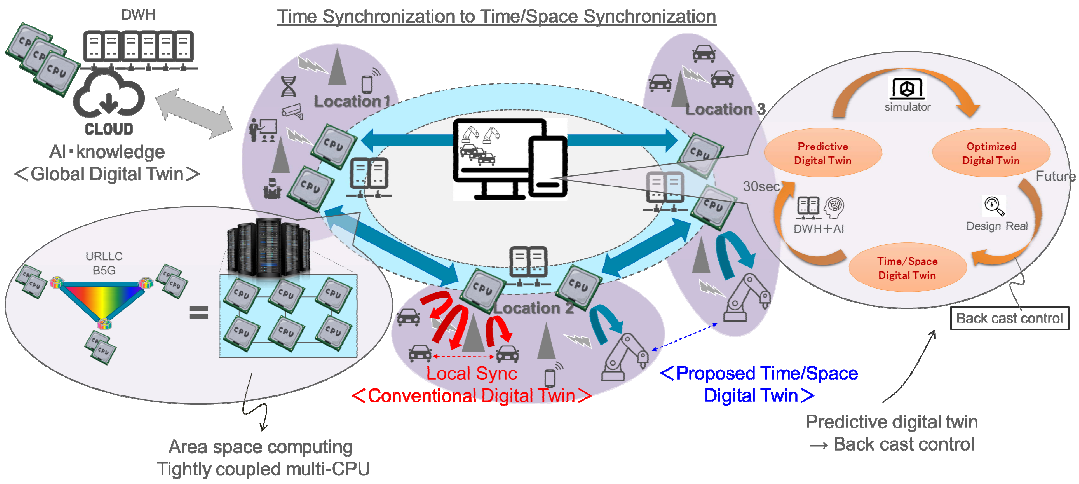

Figure 4. By time- space synchronization, idea and predictive digital twin

3. Cutting-edge optical network technology

3.1 Next generation extremely multiple access network

The MIC's Research and Development of Advanced Optical Transmission Technology Contributing to a Green Society (JPMI00316) (research representative: Oki Electric Industry) [8] is proceeding with research and development using the network architecture shown in Fig. 5. This is an economical ultra-high-speed passive optical network (PON) technology in the 400 Gbps class for distributed cloud access and a super multi-branch PON technology that covers Internet of Things (IoT) and sensors. Current PON mainly covers residential use, and it is said that reliability and bandwidth are still insufficient for mobile backhaul, cloud red and edge computing. On the other hand, devices such as IoT and sensors that use almost no bandwidth, and devices such as sensor cameras that are only used when someone is present and are turned off the rest, have also entered subscriber networks. Taking these into account, Beyond 5G is also considering super multi-branch access for economical solution.

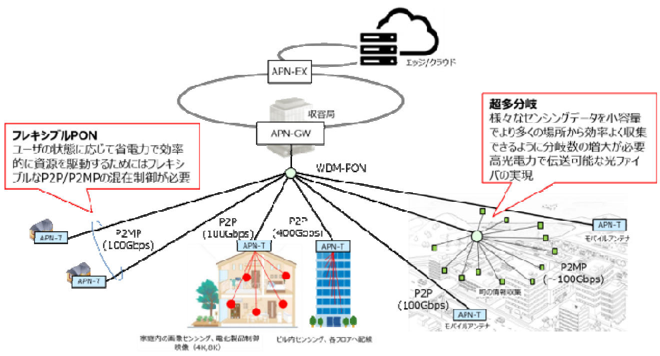

Figure 5. Next generation access network architecture by JPMI00316 project

3.2 Hollow-core fiber [9]

Figure 6 shows the structures of an ordinary single-mode fiber and a hollow core fiber. Figure 7 shows a cross-sectional photograph of the hollow core fiber[9]. There is another structure called anti-resonant type hollow core fiber[10,11] but because of better performance for real use, we use this reflection type hollow core fiber. Hollow core fibers have a crystal structure in their cladding, and the diameter of the core portion, where light is successfully confined in the air portion of the core through Bragg reflection, is larger than that of ordinary single-mode fibers. Since the core is air and refractive index of air is very small (n=1.0003), the following three major characteristics are expected.

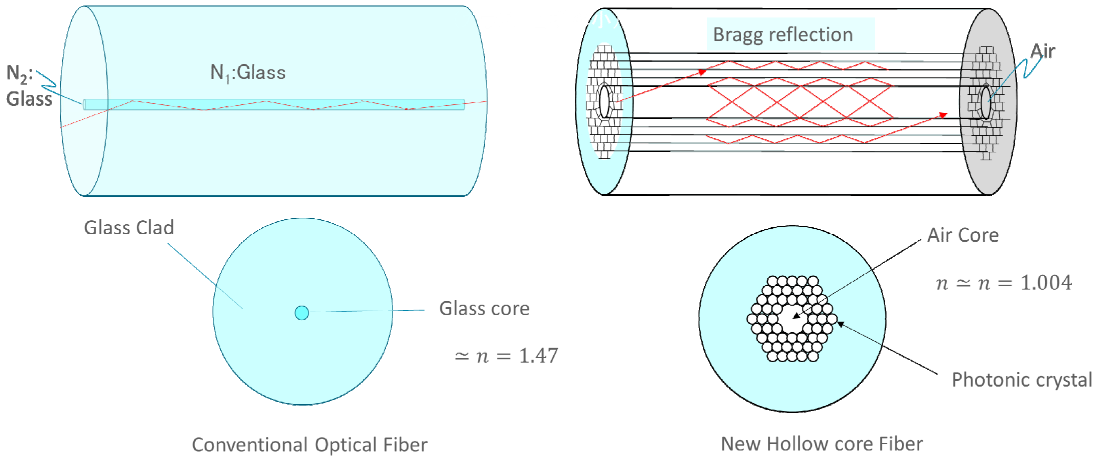

Figure 6. Image of optical transmission using hollow core fiber

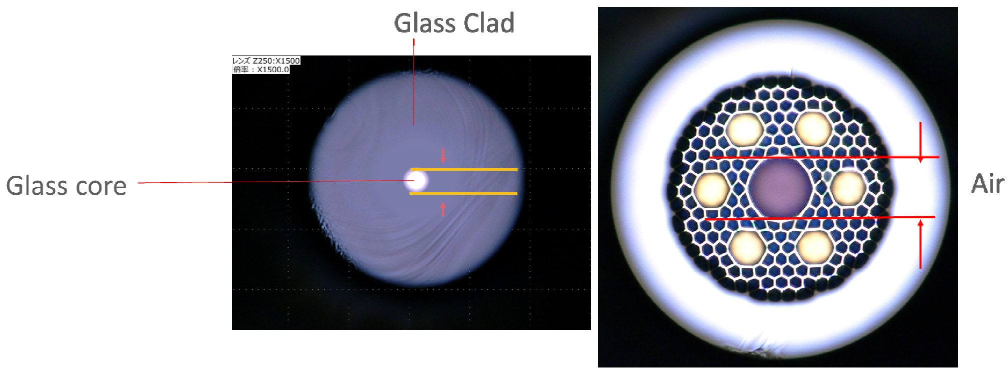

Figure 7. Cross-sectional view of hollow core fiber (Image: size adjusted)

(1) High energy transmission is possible...approximately 1000 times that of normal optical fiber.
(2) Low delay...n=c/n and n=1.0003 (C is the speed of light: 3× 108m/s), normal optical fiber is n=1.47. There are some demonstration related to low delay[12,13,14,15] this is one of the very important characteristics for Beyond 5G.
(3) Expected high linearity…no nonlinearity depending on the core material. This characteristic is new future for optical transmission[16].
From (1), there is a possibility of realizing PWoF and ultra-multi-wavelength transmission because there is a low limit on energy density increasing in proportion to the number of wavelengths. In (2), there is a possibility of a low-latency network. Regarding (3), there is a possibility of analog RoF. Below, we will discuss the research status of the latest technology.

3.3 Powe over fiber technology, PWoF

Power transmission technology using optical fibers has been pioneered by Matsuura et al.[17][18]. Furthermore, studies have begun on optical network units (ONUs) using auto-sleep ONUs and PWoF, with an eye toward introducing IoT and other services to subscribers [19]. High power transmission is also demonstrated[20]. We created the world's first optical power supply module using Hollow-core fiber. Figure 8 shows its circuit block, and Fig. 9 shows its external appearance. I would like to report the details separately.

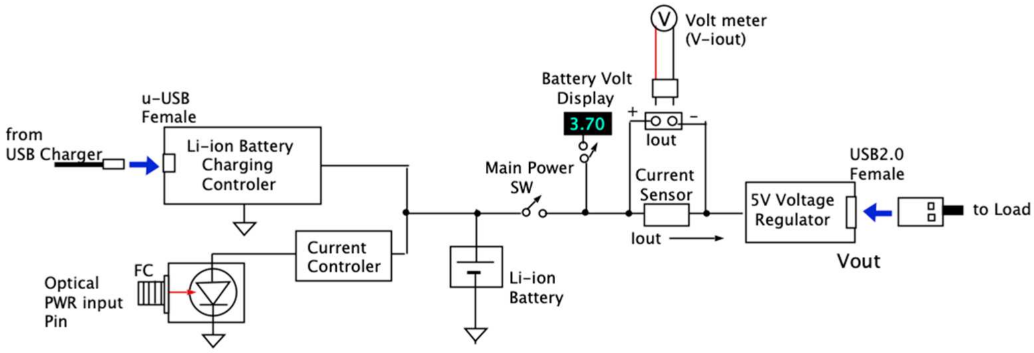

Figure 8. Circuit diagrams of Power over Fiber, PWoF

Figure 9. PWoF prototype box

3.4 Radio over fiber, RoF

Similarly, we have started experimenting with RoF using Hollow-core fiber [21]. 5G uses radio in the sub 6 GHz (sub-6) band. Furthermore, in the pursuit of broadband communications, it is important to utilize millimeter wave bands exceeding 20 GHz and THz. On the other hand, since these high-frequency bands have excellent straight-line propagation, they are greatly affected by buildings and obstacles. RoF allows antennas to be installed behind these obstacles using optical fiber, and can also complement wireless technology. We also succeeded in transmitting WiFi using RoF [22]. A photo of the module is shown in Figure 10. The Future Optical Network Open Research Center is equipped with sub-6 private 5G (called “Local 5G” in Japan) equipment. We have started experimenting with RoF using this system and Hollow-core fiber (Figure 11). We have also started experimenting with Switched-RoF/MultiSpot-RoF [7], which uses optical switches (or splitters) to selectively output wireless signals to multiple RoF antennas.

Figure 10. RoF module

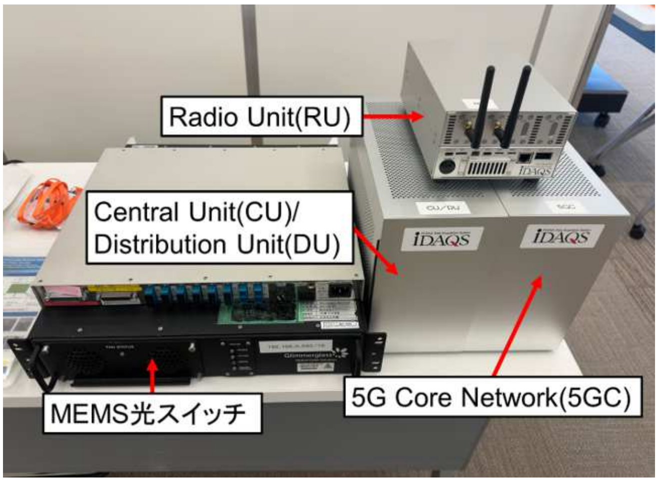

Figure 11. Local 5G system and micromachine electro mechanical system (MEMS) optical switch

3.5 Ultra-low latency network

Figure 12 shows the world's first Hollow-core fiber campus installation diagram. A newly developed cable was installed inside the manhole, making it possible to conduct research at a level close to practical use.

Figure 12. Ultra-low latency network using hollow core fiber

4. CONCLUSIONS

We have built a campus network using hollow-core fiber, aiming for a breakthrough from devices that will meet the ultra-low delay requirements of Beyond 5G. Hollow-core fibers have a air hole in the core and have succeeded in trapping light in the core. Using the characteristics of this fiber, we first reported on the current experimental results regarding the possibilities of multi-branch access, ultra-multi-wavelength networks, radio over fiber (RoF), and power over fiber (PWoF) with some experimental results. We also opened the Keio Future Optical Network Open Research Center to make these available for open use. Hollow core fiber has other capability like multi-band transmission and massively huge number of wavelength transmission with more sophisticated transmission technologies[23,24] We will expanding our research on this area.

ACKNOWLEDGEMENTS

This research was supported in part by the Ministry of Internal Affairs and Communications' Research and Development of Advanced Optical Transmission Technology Contributing to a Green Society (JPMI00316) and the National Institute of Information and Communications Technology (NICT) commissioned research (JPJ012368C07101). In addition, experiments and research were conducted at the Keio University Future Optical Network Open Research Center. This new functional fiber was developed mainly by Furukawa Electric and Dr. Kazunori Mukasa.

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