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World Record One Petabit per Second Fiber Transmission over 50-km: Equivalent to Sending 5,000 HDTV Videos per Second over a Single Fiber

NTT and three partners- Nippon Telegraph and Telephone Corporation (NTT, Chiyoda-ku, Tokyo, CEO: Hiroo Unoura), Fujikura Ltd. (Fujikura, Koto-ku, Tokyo, President and CEO Yoichi Nagahama), Hokkaido University (Sapporo, Hokkaido, President Hiroshi Saeki), and Technical University of Denmark (DTU, Lyngby, Denmark, President Anders Overgaard Bjarklev)-demonstrated ultra-large capacity transmission of 1 petabit (1000 terabit) per second over a 52.4 km length of 12-core (light paths) optical fiber.
The present achievement indicates that transmission of one petabit per second (Pbps), capacity equivalent to sending 5,000 HDTV videos of two hours in a single second is possible over 50 km, which is approximately the distance between medium-haul telecom offices. This sets a new world record throughput over a single strand of optical fiber.
This remarkable achievement was reported as a postdeadline paper[*1] on September 20, 2012 at the European Conference and Exhibition on Optical Communications (ECOC 2012), the largest conference on optical communication in Europe, that was held in Amsterdam, the Netherlands, from September 16-20, 2012.
This work was partially based on work commissioned by the National Institute of Information and Communications Technology (NICT).

1. Research Background

Recent figures by the Ministry of Internal Affairs and Communications [1] indicate that broadband services, driven by FTTH and smartphones, will continue to expand rapidly, and traffic will continue to grow apace at a rate of 1.2 times per year (a 10-fold increase in 10 years) for the foreseeable future. Efforts to increase the capacity of optical networks to accommodate surging traffic demand have largely focused on driving down infrastructure costs by using more efficient optical communications equipment to support more widespread deployment of broadband services without changing the structure of optical fiber itself. The optical fiber used in today's long-haul high-capacity optical networks has a single core-a single optical signal path-with a throughput of 1 terabit per second in the present commercial systems. Yet, due to the traffic increase, we face a serious challenge in meeting this traffic demand in the years ahead.
Addressing these concerns, Professor Toshio Morioka of the Technical University of Denmark (DTU) (formerly with NTT's Science and Core Technology Laboratory Group), conceived a novel scheme for implementing long-haul high-capacity optical networks that could support increased traffic loads into the future. Professor Morioka's proposal of developing spatial multiplexing optical communication technology[*2] including multicore optical fiber (MCF) and other novel optical fiber designs has been driving this sector ever since [2]. Indeed, Professor Morioka's proposed approach has emerged as a dominant worldwide trend in the quest for greater capacity optical communication systems. In order to assess the viability of this approach that was proposed in Japan, two companies and two universities-NTT, Fujikura, Hokkaido University, and DTU-combined their expertise to develop multicore optical fiber designs, fabrication techniques, and spectrally-efficient transmission technologies to derive maximum performance from spatial multiplexing optical communication transmission to reach the target throughput illustrated in Figure 1 .

2. Trial Demonstration and Results(See Figure 2)

With the goal of significantly improving the capacity of optical communication systems, we developed a new 12-core MCF structure with the cores arranged in a nearly concentric pattern, a novel fan-in fan-out device, and applied a digital coherent optical transmission scheme for transmitting dense wavelength division multiplexed signals in each core. The new core arrangement markedly reduced signal leakage (crosstalk) between adjacent cores, which had been a problem with conventional MCF designs. Moreover, by applying polarization multiplexed 32QAM (quadrature amplitude modulation) digital coherent technology that exploits the wave properties of light (phase[*3] and polarization[*4]) to transmit multiple signals, we successfully boosted transmission efficiency per core by more than 4 times that of the MCF transmission previously reported. This yields a transmission capacity of 84.5 terabit per second for each core (= 380 Gbps capacity per wavelength X 222 wavelength channels), for a total capacity of 1.01 petabit (= 12 X 84.5 terabit) per second for the

12-core optical MCF through 52.4 km of fiber. Because the Q-value representing communication quality is extremely uniform across all cores, this means there is little variation in quality from one core to the next, and that error-free communication is feasible (see Figure 3).

This breakthrough enabled us to achieve 1 petabit throughput capacity for the first time ever and have surpassed the previous record over conventional optical fiber [3] by more than 10 times the throughput capacity. In the new target domain made possible by spatial multiplexing optical communication technology, the present achievement has also surpassed the previous record of 305 Tbps (tera = 1 trillion) [4], to establish a new world record of 1 Pbps.

3. Technical Details and Roles

(1) Design, fabrication, and assessment of the 12-core MCF (NTT, Fujikura, Hokkaido University) (Figure 4)

With MCFs, it is important to minimize leakage of light (crosstalk) between adjacent cores while maintaining the same or better transmission loss characteristics than that of conventional optical fibers. This represents a major challenge, since previous MCF's structure with over 7 cores tends to increase crosstalk, which reduces transmission capacity in each core.

For this work, Fujikura and Hokkaido University collaborated in the design of a new structure MCF (non hexagonal-close-packed structure) that arranges the 12 cores in a near cylindrical configuration. By implementing the fiber with only 2 adjacent cores-one on the right and one on the left-crosstalk is markedly reduced compared to the typical structure MCF, and this novel design also realized low-loss characteristics. NTT evaluated the characteristics of the new structure MCF and found that the optical signal losses of each core were roughly the same as those of conventional optical fibers, inter-core crosstalk was reduced to well within design parameters, and optical characteristics were uniform among cores.

(2) Fan-in fan-out device for MCF (NTT, Fujikura) (Figure 5)

In order to use conventional transmitters/receivers, we must establish a viable device for efficiently coupling to each of the 12 cores of the MCF via conventional single mode fibers (fan-in and fan-out: stable coupling between 12 conventional fibers and a 12-core MCF). For this project, we developed a device that precisely aligns 12 separate single mode fibers that have been thinned to less than a 1/3 their regular diameter to the 12-core MCF that satisfies our fan-in fan-out requirements: low crosstalk and low insertion loss

(3) Spectrally-efficient multi-level QAM digital coherent technology (Figure 6)

Optical communication generally uses a scheme in which light signals are represented in either one of two intense states: either ON or OFF. For this project we developed an alternative approach that provides even smartphones with enough digital signal processing capability to apply and extend optical communications by creating multi-signal states using the properties of lightwaves-phase and polarization. Applying the 1's and 0's of digital signals to this multi-signal state scheme in combination with polarization multiplexed 32QAM digital coherent technology[*5], we were able to achieve stable transmission in optical MCF in the presence of some degree of crosstalk. In addition, transmission efficiency per wavelength shows close to a ten-fold improvement over conventional ON/OFF modulation.

4. Future Research

We have demonstrated key technologies for implementing a breakthrough optical communication system that dramatically boosts the transmission performance of prevailing commercial technology by over 1,000 times. With further cooperation and development of these technologies that exploit the freedom of optical fiber spatial structures, optical amplification, and spectrally-efficient transmission technologies, this will open the way to even longer distance transmission and very large capacity optical networks that support the continued rollout of broadband services in the years ahead.

References

[1] http://www.soumu.go.jp/main_content/000149220.pdf [624KB]

[2] T. Morioka, *New generation optical infrastructure technologies: "EXAT initiative" towards 2020 and beyond,* 14th Optoelectronics and Communications Conference, OECC 2009, FT4 (2009).

[3] A. Sano et al, *102.3-Tb/s (224 x 548-Gb/s) C- and Extended L-band All-Raman Transmission over 240 km Using PDM-64QAM Single Carrier FDM with Digital Pilot Tone,* OFC.NFOEC2012, PDP5C.3 (2012).

[4] J. Sakaguchi, et al, *19-core fiber transmission of 19 x 100 x 172Gb/s SDM-WDM-PDM-QPSK signals at 305 Tb/s,* OFC.NFOEC2012, PDP5C.1 (2012).

Glossary

*1 Postdeadline papers

Postdeadline papers are papers received by ECOC and other optical communication conferences after the submission deadline. Postdeadline papers are accepted after the normal deadline to give conference participants an opportunity to hear new and significant results in rapidly advancing areas. The papers to be presented are refereed and selected during the conference, and only papers judged to be excellent and compelling are accepted for presentation in postdeadline sessions.

*2 Spatial multiplexing optical communications

A generic term for large-capacity optical communication technologies that achieve equivalent or better efficiency than standard single-mode fiber by exploiting the spatial freedom inherent in multicore optical fiber, and other new structure fiber.

*3 Phase

Lightwaves exhibit the same wave-like properties as electromagnetic waves. The oscillation timing of a lightwave is called its phase. Since waves oscillate periodically, phase is characterized by degrees of freedom ranging from 0-360 degrees. Exploiting this freedom to assign different phases-say 0 degrees and 180 degrees-to represent the 1’s and 0’s of digital data, this permits data to be sent over longer distances because phase differences can be detected more sensitively than the conventional approach of turning light ON and OFF, and also supports greater throughput because it is more efficient. Communication schemes based on this approach are called *phase modulation* schemes.

*4 Polarization

Another characteristic that lightwaves have in common with electromagnetic waves is that both exhibit two independent orientations of oscillations: X axis and Y axis. These independent axes are called *polarization*, a phenomenon used in 3D movies to produce 3D images by sending different information to the right and left eyes. It it difficult for the receiver to stably detect these two polarization orientations in conventional optical communications, so only one polarization component is used. Digital coherent technology can stably differentiate two independent polarization orientations on the receiving side, so this allows more efficient large-capacity transmission by delivering independent information on each polarization.

*5 Polarization multiplexed QAM digital coherent technology

The mainstream modulation technology today is intensity modulation in which signals are sent using two distinct states-ON and OFF-to correspond to digital 0’s and 1’s. But by replacing the two intense states of ON and OFF with polarization multiplexed QAM digital coherent technology, this permits multi-value or multilevel modulation in which two independent orientations (I and Q components) are used to send different information on each of the independent polarization optical signals. By modulating the I and Q components with different multi-value signals (e.g., various values of N), each polarization signal field generates multiple (N X N) signal states based on combinations of different intensity and phase (quadrature amplitude modulation). Very efficient and highly sensitive optical transmission is made possible by mapping multi-bit (=$\log_2 N$)digital signals to these states. Applying this technique to very efficient optical transmission using conventional single-core optical fiber, NTT demonstrated a world record throughput of 102 terabit per second wavelength division multiplexing transmission.

Attachment·Reference

- Fig. 1: Large-capacity transmission technology
- Fig. 2: Experimental configuration, key technology specifications, role of each institution
- Fig. 3: Experimental results
- Fig. 4: 12-core multicore optical fiber
- Fig. 5: Multicore fiber fan-in fan-out coupling technology
- Fig. 6: Polarization multiplexed 32QAM digital coherent optical transmitter

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