Form 3

Abstract of Thesis

Name	(DIAMANTOPOULOS NIKOLAOS PANTELEIMON)
Title	Novel Applications of Few-Mode Fibers to Transmission and Switching (低次モードファイバの伝送とスイッチングへの新たな応用に関する研究)

In opposition to the rapid traffic growth and the global capacity demands, the capacity of the single-mode fiber (SMF) cables, comprising almost entirely the global fiber optic infrastructure, has seemingly reached its maximum limit. This "capacity crunch" issue has led over the recent years to the introduction of brand new fibers, which allow more than a single path for the propagating light. This solution suggests that along with the time and frequency/wavelength dimensions, a third dimension: space, could also be used to carry additional information. For this purpose, fibers with multiple cores and multiple propagating modes have been introduced.

This thesis presents a study on novel applications to transmission and switching systems based on a class of fibers called "few-mode fibers" and is based on the research that was carried out during the Ph.D. studies of the author at the Dept. Electrical, Electronics, and Information Engineering, Graduate School of Engineering, Osaka University.

Following the introduction Chapter 1, Chapter 2 focuses on the fundamentals of mode division multiplexing (MDM) transmission systems based upon multiple-input multiple-output (MIMO) digital signal processing (DSP). Starting from a general introduction on FMF and MDM, the computational complexity of MIMO-DSP for MDM links is addressed based on the maximum delay spread of the MDM channel. Modal dispersion compensation is discussed as a technique for channel spread reduction, while the impact of modal crosstalk on the channel delay spread is validated through numerical simulations. Finally, the channel of a nearly 100-km modal dispersion-compensated FMF link is experimentally estimated over the entire C-band.

Chapter 3 is devoted to the MDM/FMF deployment for future MANs, particularly in areas where underground ducts are full with old SMF cables, incapable of coping up with the coming metro traffic growth. After a brief discussion on the feasibility of real-time implementation of MIMO-DSP for MDM-MAN deployment, the required reconfigurable add/drop multiplexing (ROADM) operation is studied. For finer data granularity than the "superchannel" and for reduced crosstalk operation in ring topology MANs, mode-unbundled ROADM and bi-directional mode assignment are proposed and experimentally characterized. Finally, a 62-km ring topology MDM-MAN, composed of FMFs spans and two MDM-ROADMs is experimentally demonstrated.

In Chapter 4, a novel switching application based on mode-(de)multiplexers is proposed, in which different propagation modes inside a FMF can be addressed to different labels for switching, enabled by the mode-unbundled ROADM operation of Chapter 3. The advantages of the mode-label switching include that the processing is performed on-the-fly, requiring neither header processing nor high-speed switching, suitable for high-bandwidth, low-energy consumption data center networks. Experimental demonstrations are carried out, proving the feasibility of the proposed scheme. Finally, the impact of modal crosstalk on the mode-label switching is discussed.

For high-throughput low-latency and energy consumption "last-mile" radio access and mobile backhauling, as well as enhanced network resilience to natural disasters, Chapter 5 is concentrated on seamless digital coherent millimeter-wave (MMW) radio-over-fiber (RoF) systems, particularly for operation in the W-band (75-110 GHz) where atmospheric attenuation is very low, and discusses how MIMO-MDM/FMF can be adopted to enhance the capacity through spatial multiplexing. A proof-of-concept W-band MDM-RoF demonstration is carried out and a mitigation technique for the modal crosstalk-induced power fading is proposed.

The obtained results support the proposed FMF-based applications for future optical transmission and switching systems.

様式 7

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

Owing to the upcoming capacity growth, an update in the current telecommunications infrastructure will be required in the forthcoming years. On the other hand, the "capacity crunch" of single-mode fibers led to the invention of space multiplexing technologies such as mode division multiplexing (MDM) utilized by a class of fibers called few-mode fibers (FMFs). This thesis has presented a study on novel applications of FMFs to transmission and switching, for overcoming future limitations. The main results are summarized as following:

The computational complexity of multiple-input multiple-output (MIMO) digital signal processing (DSP) for MDM links have been addressed and modal dispersion compensation has been discussed as a technique for channel spread reduction. Also, numerical and experimental results have evaluated a ~100-km modal dispersion-compensated FMF link over the entire C-band.

MDM/FMF deployment for future metro area networks (MANs) has been studied, particularly in areas where underground ducts would be full with old SMF cables, incapable of coping up with the coming metro traffic growth. Also, for the realization of networking with finer data granularity than the "superchannel" in ring MANs, a mode-unbundled reconfigurable add/drop multiplexer (ROADM) architecture has been proposed and experimentally characterized. In addition, for the required crosstalk reduction, bi-directional mode assignment has been proposed and evaluated experimentally. Finally, a 62-km bi-directional mode assigned ring topology MDM-MAN, composed of FMFs spans and two MDM-ROADMs has been experimentally demonstrated.

A novel switching application has been proposed, in which different propagation modes inside a FMF can be addressed to different labels for switching. The advantages of the mode-label switching are that the processing is performed on-the-fly, requiring neither header processing nor high-speed switching. Experimental demonstrations over 2- and 3-spatial-mode FMF systems have been carried out, proving the feasibility of the proposed scheme.

Finally, for high-throughput, low-latency and energy consumption "last-mile" radio access and mobile backhauling, seamless digital coherent millimeter-wave (MMW) radio-over-fiber (RoF) systems has been studied, particularly for operation in the W-band where atmospheric attenuation is very low. MDM/FMF has been proposed for having the same degree-of-freedom between the optical and wireless MIMO channels with enhanced MIMO capacity through spatial multiplexing. A proof-of-concept W-band MDM-RoF demonstration has been carried out using phase modulated signals. In addition, a mitigation technique for the crosstalk-induced power fading has been proposed and successfully demonstrated over a 4×4 MIMO configuration.

From all the obtained results and findings, each proposed technique and application is expected to support FMF-based transmission and switching systems in the future optical networks.

The judging committee admits that the thesis is worth the doctoral dissertation.