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論　文　名	「Design and Management System for IP-over-CWDM Networks with Reconfigurable Optical Add/Drop Multiplexers」 （波長多重光IPネットワーク用の再構築可能な光アッド/ドロップ多重装置の設計と管理システムに関する研究）
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論文要旨

The Wavelength Division Multiplexing (WDM) technology is widely implemented in metropolitan and access networks. The WDM uses optical fibers as transmission media which have huge transmission bandwidth, low signal attenuation and low signal distortion. Since internet traffic demands increase year by year, the WDM technology which exploits optical fiber's huge bandwidth is the promising technology for future network communication. Coarse WDM (CWDM) is one type of WDM technology and 18 wavelengths are standardized for CWDM, ranging from 1271 nm to 1611 nm with 20 nm spacing.

Reconfigurable Optical Add/Drop Multiplexer (ROADM) is a common device in WDM, used for lightpath reconfiguration. The ROADM reconfigurable capability by the optical switches provides transparency to the network, eliminating the needs for optical-electrical conversion at intermediate nodes. The reconfiguration process is an important task by network administrators to search optimum routes for the lightpath reconfigurations in the network for network congestion removing.

The main objective of this thesis is to provide the design and management functions related to lightpath reconfiguration in Internet Protocol (IP)-over-CWDM networks with stackable ROADMs (S-ROADMs). The design and management functions include the optical route search, loss calculation, and judgment whether optical amplifiers are used or not. This thesis is organized in 5 chapters, described as follows:

In Chapter 1, as introduction of the thesis, broadband optical network technologies are described. The explanation gives reason on the selection of IP-over-CWDM network as the chosen domain in this research. In addition to the chosen network, the proposed and implemented S-ROADM in our experimental network also gives contribution to the strong necessity to build remote control system for effective network management. The background and motivation of this research explain some part of the network management system as main works in this thesis. In such networks as large-scale LANs and networks connecting LANs, Ethernet is a frequently used technology in physical layer.

In Chapter 2, a lightpath route management system is described. The system has been designed and implemented for IP-over-CWDM networks with bidirectional S-ROADMs. There were more than 1.3×10^5 connection possibilities in a 5-node network assuming all the nodes having the same number and colors of wavelengths. The huge possibilities are caused by the combinations of the SW states, and the SW states are changed dynamically when congestion occurs. The system can be used to search usable lightpath routes made by S-ROADMs with the specified switch states. The function is based on a ROADM graph method proposed for representing the S-ROADMs, and can list vertices for each lightpath route in the network together with the loss values. The system functions were implemented using Mathematica software, based on the proposed ROADM graph. The ROADM graph is a method which represents network devices such as ROADM, into graph such that the graph can evaluate the loss property of the whole network by the parameters set in the graph. This approach to represent such device in graph is new and no published papers were found so far. Our results show how the usable lightpaths can be searched among the huge number of possibilities. Contrary to our approach representing the dynamic changes of the network, many of the reported results were given by the approaches to the static aspect of the network.

In Chapter 3, a parallel processing capability and a flexible upgradability functions were added into the previous available system. The system can process the design and management functions composed of some sub applications in parallel in multi machines for high-speed performance. In addition, the system was designed to have a flexible upgradability, i.e. no changes of the system programs are required, when adding new functions. The system has functions to output a lightpath set with minimum number of wavelengths to groom given traffic. The system also has functions to search possible lightpath routes made by ROADMs with specified switch states, and to output the total optical losses of the routes. The system functions were implemented and evaluated with one management and 3 calculation machines for the parallel processing. The total time to obtain the results for a 5-node IP-over-CWDM network was reduced down to 65 % of the total time by the system with a single machine without parallel processing. As a result, the system enables the network administrators to design IP-over-CWDM networks and manage the lightpaths with the high-speed performance.

In Chapter 4, a monitored power pre-checking scheme was proposed and implemented in IP-over-CWDM networks with ROADMs. A bidirectional amplifier module was designed to be compatible to our proposed S-ROADM. The new amplifier module was evaluated in the network and for the purpose, the monitored power pre-checking scheme was needed for the effective amplification management during lightpath reconfigurations. The pre-checking scheme consists of 3 main processes, i.e. creating a pre-checking list with estimated optical powers, monitoring actual optical powers, and judging whether the candidate lightpaths in

the pre-checking list are amplified or not. To create the pre-checking list, the system calculates all the losses of the new lightpaths, estimates the received powers to be received by optical transceivers for the new lightpaths, and selects candidate lightpaths to be amplified. The system judges whether the lightpaths in the pre-checking list should be amplified or not by comparing the minimum detectable powers of the optical transceivers with the actual powers monitored by the system function, respectively, and sends control signals so as to switch on the amplifiers for the lightpaths to be amplified, according to the judged results. The pre-checking performance was examined in an experimental IP-over-CWDM network by reconfiguring lightpaths. As a result, the pre-checking function worked properly, and the lightpaths were reconfigured successfully even for a longer lightpath than the allowable distance, including the amplification management performance. The pre-checking function provides an effective management performance to judge which lightpaths should be amplified, before the reconfiguration.

In Chapter 5, the results obtained by this research are summarized.

審査結果の要旨

本論文は、今後のブロードバンド通信の主流である光 IP（Internet Protocol）ネットワークを、大規模 LAN (Local Area Network)やキャンパスネットワーク、地域ネットワークなどに適用する場合、トラフィック変動に柔軟に対応できる ROADM (Reconfigurable Optical Add/Drop Multiplexer)を制御する手法、特に ROADM により再構築する光パスの管理に関し、理論的、実験的な検討を行って、その評価結果を示したものである。得られた主な結果は、以下の項目に要約できる。

(1) ROADM によりネットワーク中で取り得る膨大な数の光パスの中から、使用可能な光パスを効率的に探索する手法として ROADM グラフを提案し、本提案に基づく機能を制御システムに実装してその有効性を示した。また、探索した各光パスに対し、光損失を計算する機能も合わせて実装し、動作することを示した。光損失は、ROADM を構成する光部品の 3 つの損失値をもとに、任意のルートの光パスの損失を計算でき、実験値との比較から、±1dB の精度で計算できることを明確にした。

(2)光ルート探索と光損失計算の高度化を行うため、入出力はウエブブラウザとし、処理機能を複数の計算機で分散処理するのに適したシステム構成を設計し、ウエブサーバと連動した分散処理機能を設計・実装した。3 台の計算機で分散処理することで、処理時間を 65%まで減少させ、本手法が有効であることを明確にした。

(3)長距離の光パスに対応できるよう光アンプを ROADM 中に導入する場合、光パス再構築時に、光アンプを適用すべきか否かを判断する機能を動作させた。効率的な判断をするため、光パワープリチェック構成を提案し、制御システムに実装した。実験により、本機能が動作して光アンプが正常に機能することを明確にした。

以上の結果は、光 IP ネットワークを広く適用する上で必要となる技術を進展させており、本分野の学術および産業上の発展に寄与するところ大である。また、申請者が自立して研究活動を行うのに必要な能力と学識とを有することを証したものである。

学位論文審査委員会は、本論文の審査ならびに最終試験の結果から、博士（工学）の学位を授与することを適当と認める。