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**MULTI-OBJECTIVE OPTIMIZATION FOR GROOMING, ROUTING AND  
WAVELENGTH ASSIGNMENT IN OPTICAL NETWORK DESIGN**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT  
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in Optical Network Design

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## Abstract

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In current optical technology, the data rate of a wavelength carries a huge bandwidth. In practice, the traffic demands are typically with a low rate (sub-wavelength) of a wavelength channel and the number of wavelength channels is limited on each logical link. In this dissertation, we present a Grooming, Routing and Wavelength Assignment (GRWA) design for optical networks by considering multiple design objectives. The GRWA is the problem that combines multiple low rate communication demands to use a single wavelength channel. This is to support a large number of requested demands with low-rate traffic. The design objectives are maximizing the number of accepted commodities, minimizing the number of wavelengths and minimizing the number of switching ports. Maximizing accepted commodities normally requires a large number of wavelengths and transmission ports. In contrast, minimizing the number of transmission ports could cause a large number of communication demands or commodities to be blocked or else a smaller number of accepted commodities can be served. The design objectives conflict with each other. This dissertation considers the GRWA optimization problem in the all-optical network environment. The optical data stream can be bypassed in the optical domain. A Genetic Algorithm for routing, Extended Traffic Grooming (ETG) and Maximum Degree First Wavelength Assignment (MaxDF) called GA-ETG-MaxDF or GA-EMF is proposed for solving the GRWA problem. An existing multi-objective algorithm (i.e., NSGA-II) is applied to search the set of solutions. The

obtained results are provided as candidate choices or non-dominated front for making the final selection. The obtained solutions from GA-EMF are evaluated by comparing them with the existing traffic grooming algorithms which are MRU and MST by using multi-objective performance metrics consisting of Hyper-volume, Spread and Inverted Generational Distance. Numerous non-dominated solutions can be filtered or pruned by using our Pruning mechanism called Adaptive Angle Based (ADA) technique. The non-dominated solutions after pruning are efficiently reduced to a few outstanding solutions.

**Keywords:** Grooming, Routing and Wavelength Assignment (GRWA)/ Multi-Objective Network Design/ Multi-Objective Optimization/ Pruning Mechanism

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บทคัดย่อ

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ในปัจจุบันเทคโนโลยีทางเครือข่ายใยแก้วนำแสงได้รับการพัฒนาให้ช่องความถี่หนึ่งช่องสัญญาณรองรับปริมาณข้อมูลส่งผ่านได้มหาศาล ซึ่งการเชื่อมต่อในปัจจุบันต้องการรับส่งข้อมูลไม่มากเท่ากับปริมาณความจุของข้อมูลในหนึ่งช่องสัญญาณที่มีอยู่อย่างจำกัดในสายใยแก้วเส้นหนึ่ง งานวิจัยนี้ได้นำเสนออัลกอริทึมในการแก้ปัญหาการออกแบบการรวมเส้นทางและช่องสัญญาณสำหรับเครือข่ายใยแก้วนำแสง โดยคำนึงถึงหลายวัตถุประสงค์ วัตถุประสงค์ในการออกแบบคือ ออกแบบเส้นทางและช่องสัญญาณให้รองรับการเชื่อมต่อได้มากที่สุด โดยใช้จำนวนช่องสัญญาณน้อยที่สุด และจำนวนพอร์ตสำหรับส่งผ่านข้อมูลให้น้อยที่สุด ซึ่งสมการวัตถุประสงค์ที่กล่าวมามีความขัดแย้งกัน การออกแบบให้รองรับจำนวนการเชื่อมต่อมาก ๆ จำเป็นต้องใช้ช่องสัญญาณมากไปด้วย ในทางกลับกัน การลดจำนวนช่องสัญญาณ หรือลดจำนวนพอร์ตสำหรับส่งผ่านข้อมูลจะมีผลกระทบต่อปริมาณการเชื่อมต่อเช่นกัน งานวิจัยนี้พิจารณาหาค่าที่เหมาะสมที่สุดสำหรับการรวมเส้นทางและช่องสัญญาณในสภาพแวดล้อมที่สามารถส่งผ่านข้อมูลในชั้นของแสงได้ อัลกอริทึมที่เรียกว่า GA-ETG-MaxDF หรือ GA-EMF ได้รับการพัฒนาโดยประยุกต์เข้ากับอัลกอริทึมแบบหลายวัตถุประสงค์ที่มีอยู่ในปัจจุบัน คือ NSGA-II เพื่อใช้ในการแก้ปัญหาในการออกแบบและค้นหาคำตอบที่เป็นไปได้ที่มีอยู่อย่างหลากหลาย คำตอบที่ได้จากการออกแบบหลายวัตถุประสงค์จะอยู่ในรูปของเซตคำตอบ เซตของคำตอบที่ได้สามารถเปรียบเทียบกับเซตของคำตอบที่ได้จากอัลกอริทึมในการออกแบบการรวมเส้นทางและช่องสัญญาณที่มีอยู่ในปัจจุบัน คือ MRU และ MST โดยใช้เครื่องมือในการเปรียบเทียบเซตของคำตอบแบบหลายวัตถุประสงค์ คือ Hyper-volume, Spread and Inverted Generational

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Distance เข้ามาคำนวณแปลงเซตของคำตอบที่ได้ออกมาเป็นค่าตัวเลขที่สามารถเปรียบเทียบกันได้ นอกจากนี้ คำตอบที่ได้จากอัลกอริธึมแบบหลายวัตถุประสงค์โดยทั่วไปมีจำนวนมาก ทำให้ยากในการตัดสินใจเลือกคำตอบสุดท้าย งานวิจัยนี้นำเสนออัลกอริธึมที่เรียกว่า ADA สำหรับกรอง หรือลดจำนวนเซตของคำตอบเดิมที่มีมาก ให้ลดจำนวนลงเหลือเพียงคำตอบที่เด่นชัด

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## LIST OF SYMBOLS

SYMBOL	UNIT
$N$	The set of network nodes in the network -
$E$	The set of network edges or network links in the network -
$E(i, *)$	The set of edges that leave from node $i \in N$ -
$E(*, i)$	The set of edges that go to node $i \in N$ -
$D$	The set of network edge distances -
$K$	The set of available wavelength channels -
$G$	The set of group of multiple commodities -
$Q$	The set of commodities -
$Q_A$	The number of accepted commodities -
$K_A$	The number of required/assigned wavelength -
$L$	The maximum path length (in kilometer) -
$H$	An upper-bound number of hop counts -
$\psi(o)_g^e$	The number of optical ports -
$\psi(e)_g^e$	The number of electrical ports -
$\varphi(o)_g^e$	The number of optical units -
$\varphi(s)_g^e$	The number of electrical transmitting units -
$\varphi(d)_g^e$	The number of electrical receiving units -
$T_{acc}$	The minimum accepted commodities threshold -
$K_{max}$	An upper-bound number of wavelengths -
$\delta_{q,g}^{e,k}$	The decision variable of a commodity $q \in Q$ occupies wavelength channel $k \in K$ on edge $e \in E$ and group $g \in G$ in the network -
$\beta_q$	The variable of commodity $q \in Q$ to be set up from one source to another destination -
$\phi_k$	The variable of wavelength channel $k \in K$ to be used in the network -
$F_g^e$	The set of commodities in the group $g \in G$ on network edge $e \in E$ -
$\gamma_q^k$	The variable of assigning a wavelength channel $k \in K$ to a commodity $q \in Q$ if the commodity $q$ is accepted -
$\Lambda_{q,g}$	The variable of assigning a commodity $q \in Q$ to a group $g \in G$ -
$\gamma_g^k$	The variable of assigning a group $g \in G$ to a wavelength channel $k \in K$ -
$\mathfrak{R}_g^e$	The variable of minimum bandwidth of the group $g \in G$ on edge $e \in E$ -

## LIST OF TECHNICAL VOCABULARY AND ABBREVIATIONS

ARPANET	=	Advanced Research Projects Agency Network
CHNNET	=	Chinese National Network
DWDM	=	Dense Wavelength Division Multiplexing
ETG	=	Extended Traffic Grooming
FAR	=	Fixed Alternate Routing
FF	=	First Fit
GA	=	Genetic Algorithm
GA-EMF	=	Genetic Algorithm for Routing, Extended Traffic Grooming and Maximum Degree First Wavelength Assignment
GA-ETG-MaxDF	=	Genetic Algorithm for Routing, Extended Traffic Grooming and Maximum Degree First Wavelength Assignment
GA-MinDF	=	Genetic Algorithm for Routing and Minimum Degree First Wavelength Assignment
GA-MRU-FF	=	Genetic Algorithm for Routing, Maximizing Resource Utilization and First Fit Wavelength Assignment
GA-MST-FF	=	Genetic Algorithm for Routing, Maximizing Single-Hop Traffic and First Fit Wavelength Assignment
GRWA	=	Grooming, Routing and Wavelength Assignment
MinDF	=	Minimum Degree First Wavelength Assignment
MO	=	Multi-Objective
MOGA	=	Multi-Objective Genetic Algorithm
MP2P	=	Multi-Point to Point
MP2MP	=	Multi-Point to Multi-Point
MRU	=	Maximizing Resource Utilization
MST	=	Maximizing Single-Hop Traffic
MaxDF	=	Maximum Degree First Wavelength Assignment
NP	=	Non-Polynomial
NPGA	=	Niched Pareto Genetic Algorithm
NSFNET	=	National Science Foundation Network
NSGA	=	Nondominated Sorting Genetic Algorithm
NSGA-II	=	Fast Non-dominated Sorting Genetic Algorithm
OEO	=	Optical-Electronic-Optical Switching
PAES	=	Pareto-Archived Evolution Strategy
P2P	=	Point to Point
P2MP	=	Point to Multi-Point
RWA	=	Routing and Wavelength Assignment
RWGA	=	Random Weighted Genetic Algorithm
SPEA	=	Strength Pareto Evolutionary Algorithm
SPEA2	=	The Improving of Strength Pareto Evolutionary Algorithm
SSE	=	Sum of Squared Error
VEGA	=	Vector Evaluated Genetic Algorithm
WBGA	=	Weight-Based Genetic Algorithm
WDM	=	Wavelength Division Multiplexing