



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

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
(ELECTRICAL AND COMPUTER ENGINEERING)
FACULTY OF ENGINEERING
KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

2010

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in Optical Network Design

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A Dissertation Submitted in Partial Fulfillment
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Faculty of Engineering
King Mongkut's University of Technology Thonburi
2010

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Dissertation Title	Multi-Objective Optimization for Grooming, Routing and Wavelength Assignment in Optical Network Design
Dissertation Credits	36
Candidate	Mr. Pakorn Leesutthipornchai
Dissertation Advisor	Assoc. Prof. Dr. Naruemon Wattanapongsakorn
Dissertation Co-advisor	Dr. Chalernpol Charnsripinyo
Program	Doctor of Philosophy
Field of Study	Electrical and Computer Engineering
Department	Computer Engineering
Faculty	Engineering
B.E.	2553

Abstract

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

หัวข้อวิทยานิพนธ์	การหาค่าที่เหมาะสมที่สุดหลายวัตถุประสงค์สำหรับการรวมเส้นทางและช่องสัญญาณในการออกแบบเครือข่ายใยแก้วนำแสง
หน่วยกิต	36
ผู้เขียน	นายปรกรณ์ ลีสุทธิพรชัย
อาจารย์ที่ปรึกษา	รศ.ดร.นฤมล วัฒนพงษ์กร
อาจารย์ที่ปรึกษาร่วม	ดร.เจติมพล ชาญศรีภิญโญ
หลักสูตร	ปรัชญาดุษฎีบัณฑิต
สาขาวิชา	วิศวกรรมไฟฟ้าและคอมพิวเตอร์
ภาควิชา	วิศวกรรมคอมพิวเตอร์
คณะ	วิศวกรรมศาสตร์
พ.ศ.	2553

บทคัดย่อ

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

Distance เข้ามาคำนวณแปลงเซตของคำตอบที่ได้ออกมาเป็นค่าตัวเลขที่สามารถเปรียบเทียบกันได้ นอกจากนี้ คำตอบที่ได้จากอัลกอริทึมแบบหลายวัตถุประสงค์โดยทั่วไปมีจำนวนมาก ทำให้ยากในการตัดสินใจเลือกคำตอบสุดท้าย งานวิจัยนี้นำเสนออัลกอริทึมที่เรียกว่า ADA สำหรับกรอง หรือลดจำนวนเซตของคำตอบเดิมที่มีมาก ให้ลดจำนวนลงเหลือเพียงคำตอบที่เด่นชัด

คำสำคัญ : การออกแบบการรวมเส้นทางและช่องสัญญาณ/ การออกแบบเครือข่ายแบบหลายวัตถุประสงค์/ เทคนิคการหาคำตอบที่ดีที่สุดแบบหลายวัตถุประสงค์/ อัลกอริทึมสำหรับลดจำนวนเซตของคำตอบแบบหลายวัตถุประสงค์

ACKNOWLEDGEMENTS

First, I would like to greatly acknowledge Assoc. Prof. Dr. Naruemon Wattanapongsakorn and Dr. Chalernpol Charnsripinyo, who always gave me advice, contributions, and other help during the period of my study. I appreciate Prof. David W. Coit, who gave me many academic suggestions, and Asst. Prof. Poompat Saengudomlert, who gave me a recommendation to the foreign professor. I specially thank all committee members advising in the dissertation examination. I have to be grateful to all lecturers who have instructed me and all officers who have always offered me willing help. Sincerely thanks are extended to my senior friends and colleges for their friendship and help. I would like to acknowledge the Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD 0045/2550) and King Mongkut's University of Technology Thonburi (KMUTT) for financial support. Finally, I would like to give my special thanks to my family, father, mother, and aunt. Their support and encouragement were the essence that helps me through the three years of my study.

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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	-
β_q	The variable of commodity $q \in Q$ to be set up from one source to another destination	-
ϕ_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 $e \in E$	-
γ_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 $g \in G$	-
γ_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