Analyse de performance des réseaux optiques à commutation en sous-longueur d'onde

Raluca Maria Indre

ParisTech
INSTITUT DES SCIENCES ET TECHNOLOGIES
PARIS INSTITUTE OF TECHNOLOGY

TELECOM ParisTech

2012-ENST-061

EDITE - ED 130

Doctorat ParisTech

T H È S E

pour obtenir le grade de docteur délivré par

TELECOM ParisTech

Spécialité « Informatique et réseaux »

présentée et soutenue publiquement par

Raluca-Maria INDRE

le 5 novembre 2012

Performance Analysis of Subwavelength Switching Optical Networks

Directeur de thèse : **Thomas BONALD**
Co-encadrement de la thèse : **Sara OUESLATI**

Jury

M. Andrea BIANCO, Professeur, Politecnico di Torino	Rapporteur
M. Pablo PAVÓN MARIÑO, Maître de conférences, Technical University of Cartagena	Rapporteur
M. Tijani CHAHED, Professeur, Télécom SudParis	Examinateur
M. Maurice GAGNAIRE, Professeur, Télécom ParisTech	Examinateur
M. Yvan POINTURIER, Docteur, Alcatel-Lucent Bell Labs	Examinateur
M. Thomas BONALD, Professeur, Télécom ParisTech	Directeur de thèse
Mme. Sara OUESLATI, Docteur, France Telecom Orange	Co-encadrante de thèse

TELECOM ParisTech
école de l'Institut Mines-Télécom - membre de ParisTech

THÈSE

Telecom Paristech
Orange Labs

Performance Analysis of Subwavelength Switching Optical Networks

- Ph.D. Thesis -

Raluca-Maria Indre

Academic Advisor: Thomas Bonald
Orange Labs Co-Advisors: Bruno Kauffmann, Philippe Olivier, Sara Oueslati

June 25, 2013

Părinţilor mei,
Pentru tot ce au făcut, fac şi vor face pentru noi.

Acknowledgment

I would like to express my deepest gratitude to my academic advisor Thomas Bonald. I am grateful for the guidance he provided, for his support and for his availability. Despite his numerous responsibilities, Thomas always found the time for the work we carried out together. Throughout these three years his valuable insights and advices have pushed my research activity in the right direction. It has been an honour for me to have Thomas as my advisor.

I sincerely thank my Orange Labs advisors Sara Oueslati, Philippe Olivier and Bruno Kauffmann. I thank Sara for giving me the opportunity to do this Ph.D., for believing in me, for supporting me and for the time she dedicated to my thesis even after leaving from Orange Labs. The internship that I carried out under her supervision has greatly contributed to my decision to do a Ph.D. I thank Philippe for having accepted to be my advisor, for his repeated encouragements and for the kindness he has shown me. I am very grateful to Bruno and Philippe for the time and effort they have spent for reviewing my thesis and for their constructive comments and suggestions. Bruno has been of great support during the final part of my Ph.D. and I sincerely thank him for it. His useful suggestions largely contributed to improving the quality of my dissertation. I am also thankful to Daniel Kofman for having kindly accepted to be my Ph.D. advisor at the very beginning of this thesis.

I am truly grateful to James Roberts with whom I have had the honour and pleasure of working. James has been like an advisor for me and I am thankful for his guidance, his help, his patience, his availability and his numerous explanations. I have enjoyed our discussions and learned from his scientific rigour.

I am thankful to Andrea Bianco and Pablo Pavón Mariño for the time and effort they have dedicated in reviewing my thesis and for their constructive comments and remarks. I would like to sincerely thank Andrea for the guidance he provided during my stay at Politecnico di Torino and for his efforts to make my stay in Torino a pleasant and enriching experience. I would also like to thank Tijani Chahed, Maurice Gagnaire and Yvan Pointurier for having accepted to be part of my Ph.D. examination committee.

I am extremely grateful to my managers from Orange Labs Nabil Benameur and Prosper Chemouil for their support, their interest in my research, the opportunities they

have given me and the freedom and trust they have granted me. I am particularly thankful for the efforts they have made to facilitate my 2-months visit to Politecnico di Torino.

During these past three years I have had the pleasure and privilege to collaborate with a number of talented researchers that I would like to acknowledge here. A very special thanks to Chloé Rolland and Davide Cuda with whom I have collaborated closely. I would like to thank both of them for their help, their repeated encouragements and for the things they have taught me about life and networks. I enjoyed our joint research and learned much in the process. I am grateful to the members of the SOAN team and in particular to Esther Le Rouzic for her valuable inputs, the support she provided and for the numerous discussions on switching technologies which have helped me forge a broader view of optical networks. I would also like to sincerely thank Alain Simonian and Ludovic Noirie for their time, their kindness and their contribution to my research.

I am very grateful to the members of the TRM team which have provided a very pleasant working environment. I have greatly appreciated our talks, our coffee breaks and our meals and feel lucky to have had colleagues such as you. A very special thank you to my dear friends Amel, Alexandre, Max, Medori, Michael, Pierre and Yuhui with whom I have shared the good and the bad times during these three years. Thank you for listening, thank you for your advices, thank you for making me laugh and thank you for forcing me to take a break from time to time. It has been my good fortune to have shared this journey with you. A big thank you also to Mayssa and Chahinez with whom I have shared my office. Thank you for your good mood and for sharing your experience with me. Mayssa's numerous advices and encouragements during the final period of my Ph.D. have been of great help and comfort.

I also thank the members of the LINCS research laboratory and in particular Ahlem, Claudio, Fabien, Giuseppe, Konstantinos, Marco, Mattia, Raul and Xavier who always had a good advice, a kind word or a good joke to share. I am very grateful to all of them.

A very sincere thank you goes to my brother Marius and to his wife Delia who have always been there when I needed them. I would also like to thank Jean-Louis and Catherine for their useful advices and invaluable moral support. I dedicate this thesis to my parents as I would have never gotten this far without their timely encouragements and unconditional support. Last, but certainly not least, I would like to thank Nicolas for believing in me more than I was ever be able to.

Abstract

A key challenge in today's networks is to bridge the gap between high-speed optical transmission and limited electronic processing. This can be achieved by enabling payload to be switched directly in the optical domain. A simple solution to provide optical switching is by allocating one wavelength channel to each source-destination pair, a technique called Optical Circuit Switching (OCS). Due to lack of sharing, OCS suffers from limited scalability. To overcome this issue, the capacity of each wavelength channel must be dynamically shared among different source-destination pairs. This requires data to be switched at subwavelength granularity by means of *subwavelength switching*.

In this thesis, we propose several solutions which enable subwavelength switching in optical networks. To show the relevance of the proposed solutions, we analyse their performance in terms of traffic capacity, flow throughput and packet delay. Performance is evaluated both through simulations and by means of appropriate queueing models.

We first consider the case of Metropolitan Area Networks (MAN) and we study the performance of synchronous time-slotted Wavelength Division Multiplexing (WDM) ring in which network nodes communicate by inserting and extracting data from time-slots. We present a fully distributed Media Access Control (MAC) protocol designed to ensure fairness. We also propose a burst assembly mechanism able to ensure low assembly delays and high fill rates of the optical time-slots.

We then propose subwavelength switching solutions which can be applied in the more general case of asynchronous wide area networks. We first propose to solve the contention problems of conventional Optical Burst Switching (OBS) and the low utilization issue of wavelength-routed OBS by implementing a two-way reservation OBS scheme in which the size of the optical burst increases proportionally with the network load so as to maximize resource utilization.

Next, we propose a solution for building an all-optical wide area network based on multipoint-to-multipoint lightpath sharing. We also design an associated MAC protocol and a dynamic bandwidth allocation algorithm and analyse the performance of the proposed solution. By means of a case study, we show that the proposed solution has the potential to considerably reduce power consumption with respect to current router-based architectures. Finally, we propose a novel optical device able to solve contention directly in the optical domain without requiring any optical buffering, electronic signalling or header processing. We show that this simple device can be used as a building block for dynamic and power-efficient short-range optical networks such as access networks or data centers.

Résumé

Un défi majeur dans les réseaux d'aujourd'hui est de combler l'écart entre la haute vitesse de la transmission optique et la vitesse plus limitée du traitement électronique des données. Une option est de commuter les données directement dans le domaine optique. Dans cette thèse, nous proposons plusieurs solutions permettant la commutation dans le domaine optique à une granularité plus fine que la longueur d'onde, technique que nous appelons commutation sous-longueur d'onde. Pour montrer la pertinence des solutions proposées, nous analysons leur performance en termes de capacité de trafic, de débit et de délai. La performance est évaluée à la fois par des simulations et en utilisant des modèles de files d'attente appropriés.

Nous considérons d'abord le cas des réseaux métropolitains (Metropolitan Area Networks, MAN) et nous étudions la performance d'un anneau optique avec multiplexage en longueur d'onde (Wavelength Division Multiplexing, WDM) dans lequel la communication entre les nœuds du réseau se fait par insertion/extraction de données dans des créneaux temporels. Nous présentons un protocole entièrement distribué conçu pour assurer l'équité dans ce réseau. Nous proposons également un mécanisme d'assemblage de paquets capable d'assurer des délais faibles ainsi que des taux de remplissage élevés.

Nous proposons ensuite des solutions de commutation sous-longueur d'onde qui peuvent être appliquées dans le cas plus général des réseaux asynchrones. D'abord, nous proposons de résoudre le problème des collisions de la commutation optique par rafale (Optical Burst Switching, OBS) par la mise en œuvre d'un mécanisme de réservation. Afin de maximiser l'utilisation des ressources, nous proposons d'adapter la taille de la rafale optique à la charge du réseau.

Ensuite, nous proposons une solution alternative pour construire un réseau coeur tout-optique. A cette architecture, nous associons un protocole d'accès ainsi qu'un algorithme d'allocation dynamique de bande passante et nous analysons les performances de la solution proposée. Par le biais d'une étude de cas, nous montrons que notre solution est capable de réduire considérablement la consommation énergétique par rapport aux architectures actuelles basées sur des routeurs IP. Enfin, nous proposons un nouveau dispositif optique capable de résoudre la contention directement dans le domaine optique. Nous montrons que ce dispositif simple peut être utilisé pour construire des réseaux optiques dynamiques à courte portée tels que les réseaux d'accès ou les centres de traitement de données.