Program Overview

Sunday

10:00 - 12:00 Registration

12:00 - 14:00 Lunch (on your own)

14:00 - 14:15 Opening Session

14:15 - 15:00 SP: Plenary Session (page 20)

15:00 - 15:15 break

15:15 - 16:30 SC: Parallel Sessions (page 24)

16:30 - 16:50 Coffee break

16:50 - 18:30 SD: Parallel Sessions (page 28)

19:00 - 20:00 Welcome Reception

Monday

8:00 - 9:30 Registration

8:00 - 8:45 MP: Plenary Session (page 21)

8:45 - 9:00 break

9:00 - 10:15 MA: Parallel Sessions (page 34)

10:15 - 10:30 Coffee break

10:30 - 12:10 MB: Parallel Sessions (page 37)

12:10 - 14:00 Lunch (on your own)

14:00 - 15:40 MC: Parallel Sessions (page 41)

15:40 - 16:00 Coffee break

17:00 - 19:00 Lisbon Tour

19:30 - 22:00 Conference dinner

Tuesday

9:30 - 10:15	TP: Plenary Session (page 22)
10:15 - 10:30	Coffee break
10:30 - 12:10	TB: Parallel Sessions (page 46)
12:10 - 14:00	Lunch (on your own)
14:00 - 15:00	Doctoral Dissertation Session (page 58)
15:00 - 15:15	break
15:15 - 16:30	TC: Parallel Sessions (page 50)
16:30 - 16:45	Coffee break
16:45 - 18:00	TD: Parallel Sessions (page 53)
18:00 - 18:30	Closing Session and Dissertation Award Prize

Program Summary

Sunday, 2 March, 2014			
10:00 - 12:00	Registration: Registration desk (hall)		
12:00 - 14:00	Lunch (on your own)		
14:00 - 14:15	Opening Session: room Miguel Ângelo II		
14:15 - 15:00	**Session SP**: room Miguel Ângelo II **Martin Grötschel** **Optimization problems arising in FTTx-planning** Chair: Luís Gouveia		
15:00 - 15:15	break		
15:15 - 16:30	**Session SC-I** **Decompositions methods for network routing** Chair: Bernard Fortz	**Session SC-II** **Robust optimization I** Chair: Adam Ouorou	**Session SC-III** **Survivability networks I** Chair: Abdullah Konak
	Tiziano Parriani A study of trade-offs in decomposition approaches to multicommodity network flows	S. Raghavan Robust Optimization for the Connected Facility Location Problem	Ana Bautzer ILP formulations for a Steiner multi-ring network design problem with revenues
	Dimitri Papadimitriou Combined network design and routing optimization using distributed Benders decomposition	Walid Ben-Ameur Multipolar Routing	Pedro Patrício Lexicographical Minimization of Routing Hops in Hop-Constrained Node Survivable Networks
	Bernard Fortz Time-dependent combined network design and routing optimization	Adam Ouorou Robust models for LP with uncertain right hand side - applications to capacity assignment in telecommunications	Abdullah Konak Two-Edge Disjoint Survivable Network Design Problem with Relays: A Hybrid Genetic Algorithm and Lagrangian Heuristic Approach
16:30 - 16:50	Coffee break: Atrium		
16:50 - 18:30	**Session SD-I** **Traffic engineering** Chair: Stefano Coniglio	**Session SD-II** **Network trees I** Chair: S. Raghavan	**Session SD-III** **Optical transport networks** Chair: Amaro de Sousa
	Souad Ezzbady Contribution to Modeling and Maximizing Processing in a Network of Telecommunication	Pedro Moura Spanning Trees with variable degree bounds	Agostinho Agra Design of Optical Transport Networks: the Combined Traffic Grooming, Routing and Wavelength Assignment Problem
	Jūlija Asmuss On Fuzzy Logic Based Decision Making for Dynamically Adaptive Bandwidth Allocation	Cristina Requejo Inference of a routing network topology	Amal Benhamiche Branch-and-Cut algorithm for the Optical Multi-Band Network Design problem
	Carlos Martins Modelling the steering of international roaming traffic problem	Walid Ben-Ameur Design of networks with unicyclic connected components	Andreas Bley An exact algorithm for spectral assignment in flexible WDM grid optical networks
	Stefano Coniglio Bilevel optimization models for traffic engineering with elastic demands and fair flow allocation	S. Raghavan Local Search for the Reload Cost Spanning Tree Problem	Amaro de Sousa The Routing and Wavelength Assignment Problem in the Optical Transport Networks Design
19:00 - 20:00	Welcome Reception: Hotel bar		

Monday, 3 March, 2014

8:00 - 9:30	Registration: Registration desk (hall)	
8:00 - 8:45	**Session MP**: room Miguel Ângelo II **Thomas Bonald** **Bandwidth sharing models for the Internet** Chair: Adam Ouorou	
8:45 - 9:00	break	
9:00 - 10:15	**Session MA-I** **Multicommodity network routing** Chair: Eli Olinick	**Session MA-II** **Security and emergency** Chair: Sadan Kulturel-Konak
	Michal Pióro New Results on Multipath Routing	Bhawani Bhati A Location Privacy Preserving scheme for Routing in MANET Using Rough Sets
	Walid Ben-Ameur Efficient algorithms for the maximum concurrent flow problem	Michael Bartolacci An Optimization Model for Portable Base Stations in Disaster Planning and Management
	Eli Olinick Empirical Analysis of a Compact Formulation of the Network Design Problem	Sadan Kulturel-Konak A Bi-level Genetic Algorithm Approach for the Network Server Assignment Problem
10:15 - 10:30	Coffee break: Atrium	
10:30 - 12:10	**Session MB-I** **Network trees II** Chair: Maurício Resende	**Session MB-II** **Optical access networks** Chair: Axel Werner
	Alessandro Hill Optimal capacitated ring trees	Mateusz Żotkiewicz Large-scale FTTH network design
	Eric Gourdin Packing and Scheduling of Steiner Trees for Data Synchronization	Maria João Lopes Single PON network design with unconstrained splitting stages
	Martim Moniz Models for traffic engineering with multiple spanning tree protocols	Alejandro Arbelaez A Local Search Approach to Finding Distance-Constrained Disjoint Paths in Long-Reach Passive Optical Networks
	Maurício Resende A biased random-key genetic algorithm for a prize-collecting directed Steiner forest network design problem	Axel Werner Multicriteria optimization for optical access network planning
12:10 - 14:00	Lunch (on your own)	
14:00 - 15:40	**Session MC-I** **Reliability networks** Chair: Stefan Voß	**Session MC-II** **Economics and mobile applications** Chair: Paulo Cordeiro
	Eduardo Moreno Topological optimization of reliable networks under failure correlation	Kholoud Dorgham A Novel Dynamic Pricing Model for the Telecommunications Industry
	Robert Doverspike Performability Analysis of a Metro Area Cellular Network	Ramiro Sámano-Robles Network and economic trade-off performance regions of carrier sense multiple access protocols with cooperative diversity using multi-objective and financial portfolio optimization
	Filipa Carvalho Integer models for diameter-bounded clusters resilient to a link failure	Angele Hamel Models for Video-on-Demand Scheduling with Costs
	Stefan Voß New Algorithms for the Reliability Redundancy Allocation	Paulo Cordeiro HEVC Video Streaming Decoding Complexity Analysis
15:40 - 16:00	Coffee break: Atrium	
17:00 - 19:00	Lisbon Tour: Meeting point at the hotel Parking lot	
19:30 - 22:00	Conference Dinner	

Tuesday, 4 March, 2014

9:30 - 10:15	**Session TP**: room Miguel Ângelo II **Guy Leduc** **Machine learning-based algorithms to infer end-to-end network performance matrices** Chair: Bernard Fortz	
10:15 - 10:30	Coffee break: Atrium	
10:30 - 12:10	**Session TB-I** **Stochastic related problems** Chair: Michael Bartolacci	**Session TB-II** **Robust optimization II** Chair: Sara Mattia
	Gonçalo Jacinto Hop count performance analysis for the furthest and nearest routing protocols in sensor networks	Paolo Detti A Robust Optimization Model for Radio Resource Assignment in OFDMA Wireless Networks
	Yoshiaki Shikata Prioritized Limited Round-Robin System with its Performance Analysis	Jonad Pulaj A Hybrid Heuristic for Robust Multiperiod Network Design
	S. Raghavan An Inexact Sample Average Approximation Approach for the Stochastic Connected Facility Location Problem	Daniel Schmidt Solving a robust network design problem with simple polyhedral demand uncertainties
	Michael Bartolacci Buffer overflow simulation in self-similar queuing networks with finite buffer capacity	Sara Mattia The robust network loading problem with static routing
12:10 - 14:00	Lunch (on your own)	
14:00 - 15:00	**Doctoral Dissertation Competition**: room Miguel Ângelo II Chair: Robert Doverspike	
	Manuel Kutschka Robustness Concepts for Knapsack and Network Design Problems under Data Uncertainty	
	Faiz Hamid A Polyhedral Approach for Solving the Two-Facility Network Design Problem	
15:00 - 15:15	break	
15:15 - 16:30	**Session TC-I** **Energy aware routing** Chair: Bernardetta Addis	**Session TC-II** **Wireless networks** Chair: Alexandre Cunha
	Dorabella Santos Energy Efficient Routing for Telecommunication Networks with Multi-Period Traffic Demands	Artur Tomaszewski Design of Optical Wireless Networks with Elastic Traffic Flows
	Frank Pfeuffer Energy efficient network operation with a limited number of network configurations	Fabian Castaño Exact approaches for power aware configuration of wireless sensor networks
	Bernardetta Addis On the Energy Cost of Resiliency in IP Networks	Alexandre Cunha Models and heuristic for Integrating Sink Location, Density Control and Routing Problems in Wireless Sensor Networks
16:30 - 16:45	Coffee break: Atrium	
16:45 - 18:00	**Session TD-I** **Survivability networks II** Chair: Walid Ben-Ameur	**Session TD-II** **Energy aware network design** Chair: Arie Koster
	Bin Hu Algorithms for Link Protection Problems in Networks	Bernard Gendron A Branch and Benders Cut Approach for Nonlinear Location-Design in Green Wireless Local Area Networks
	Yoann Fouquet An optimization model for communication networks resilient to partial multiple link failures	Martin Tieves Network Design with Compression I: A Polyhedral Study
	Walid Ben-Ameur Failure-disjoint paths	Arie Koster Network Design with Compression II: A Complexity Study
18:00 - 18:30	Closing session and Dissertation Prize Award : Miguel Ângelo II	

Plenary Sessions

SP

Sunday, 14:15 - 15:00
Room: Miguel Ângelo II
Plenary Talk
chair: Luís Gouveia

Optimization problems arising in FTTx-planning

Martin Grötschel, *ZIB, TU Berlin*, groetschel@zib.de

FTT is an abbreviation of "**F**iber **T**o **T**he", whereas **x** is a placeholder for various objects to which fiber is supposed to be connected to. The most common versions are fiber to the home (FTTH), fiber to the building (FTTB), fiber to the curb (FTTC), or fiber to the neighborhood (FTTN). FTTx network planning is the task to solve all problems arising in the context of connecting all or some customers in a relatively small deployment area to one or more central offices using optical fiber and potentially existing copper cables and possibly passive concentrators in such a way that many side-constraints are satisfied and certain costs are minimized. The rollout of such networks has begun the world over, and network-providers are seeking for means to keep the very high costs for establishing such an infrastructure under control. Based on a recent survey paper written by Christian Raack, Axel Werner and myself, I will present a (practically unsolvable) very general mathematical model of FTTx-planning that takes almost all aspects of this complex task into account, and I will indicate how simplifications of this general model can be employed to support the associated decision making. Solutions of some instances from practice will be shown.

MP

Monday, 8:00 - 8:45
Room: Miguel Ângelo II
Plenary Talk
chair: Adam Ouorou

Bandwidth sharing models for the Internet

Thomas Bonald, *Telecom Paris Tech*, thomas.bonald@telecom-paristech.fr

Efficient network engineering requires a sound knowledge of the random nature of traffic and the impact of statistical multiplexing. In this talk, we give an overview of the Internet bandwidth sharing models developed over the last decade to relate capacity, demand and performance. The derived expressions constitute the basis of a new teletraffic theory which is in many ways the analogue of that founded by Erlang and Engset one hundred years ago for engineering the telephone network.

TP

Tuesday, 9:30 - 10:15
Room: Miguel Ângelo II
Plenary Talk
chair: Bernard Fortz

Machine learning-based algorithms to infer end-to-end network performance matrices

Guy Leduc, *Research Unit in Networking, Université de Liège*, guy.leduc@ulg.ac.be
Co-author(s): Yongjun Liao, Wei Du and Pierre Geurts

The knowledge of end-to-end network performance metrics is essential to many Internet applications. As active probing of all pairwise paths is infeasible in large-scale networks, a natural idea is to measure a few pairs and to predict the other ones without actually measuring them. We formulate this prediction problem as matrix completion where unknown entries of an incomplete matrix of pairwise performance metrics are to be predicted. The problem is solvable because strong correlations among network path properties exist and cause the constructed matrix to be low rank. The new formulation circumvents the well-known drawbacks of existing approaches based on Euclidean embedding. In particular, it is applicable to various, possibly asymmetric and non additive, metrics, such as round trip times and bandwidth. It can also be used for rating network paths, i.e. predicting quantized measures of path properties. Compared to fine-grained measurement, coarse-grained ratings are appealing in that they are not only informative but also cheap to obtain. By observing similarities to recommender systems, we show that our inference problem can be solved by a class of matrix factorization techniques. We have also investigated the usability of rating-based network measurement and inference in applications. A case study is performed on whether locality awareness can be achieved for overlay networks of Pastry and BitTorrent using inferred ratings. We show that such coarse-grained knowledge can improve the performance of peer selection and that finer granularities do not always lead to larger improvements.

Parallel Sessions

Sunday

SC-I

15:15 - 16:30
Room: Miguel Ângelo I

Decompositions methods for network routing

chair: Bernard Fortz

1 - A study of trade-offs in decomposition approaches to multicommodity network flows

Tiziano Parriani, *DEI, University of Bologna*, tiziano.parriani@unibo.it
Co-author(s): Alberto Caprara, DEI - University of Bologna; Antonio Frangioni (frangio@di.unipi.it), DI, University of Pisa.

When solving linear minimum cost multicommodity flow problems, the typical block-angular structure of the resulting constraint matrix can be exploited by using cost decomposition approaches, such as the Dantzig-Wolfe decomposition. This may be very effective, but in some cases (*e.g.* in presence of few commodities and/or unstable dual solutions) slow convergence issues may arise that may result in poor overall performances. Nowadays, in fact, the direct application of state-of-the-art commercial software to the natural "node-arc" formulation of the problem can be more effective than a Dantzig-Wolfe decomposition approach that uses a standard unstabilized "arc-chain" formulation for the master problem. However, there are several alternative formulations for the (possibly stabilized) master problem, that present a wide range of trade-off between the number of iterations and the required computation time for solving it, depending on the different characteristics of the instances. We computationally explore this trade-off on several sets of instances and compare the computational results with the ones obtained by directly solving the node-arc formulation, showing that appropriately choosing the master problem problem formulation (comprised the stabilization) may make decomposition approaches more competitive.

Keywords: Multicommodity flows, cost decomposition, stabilization.

2 - Combined network design and routing optimization using distributed Benders decomposition

Dimitri Papadimitriou, *Alcatel-Lucent*, dimitri.papadimitriou@alcatel-lucent.com
Co-author(s): Bernard Fortz (bernard.fortz@ulb.ac.be), ULB.

Distributed control functions of today's communication networks such as routing and resource control inherit their design from processing capacity and memory constraints. Hence, the routing decision process (distributed and online) remains decoupled from the resource control process (centralized and offline). The latter does not account for the distributed nature of the routing process because resource optimization (network design) is not decomposed along the same dimensions as the routing process. The challenge consists thus in modifying the routing decision process to include resource optimization objectives and making the optimization problem aware of the distributed nature of the routing decision process under dynamic conditions. The combined network design and distributed routing optimization problem can be formulated as a large-scale multi-period mixed integer optimization problem. Its resolution on realistic instances is however intractable and unscalable with state-of-the-art solvers which ignore the distributed nature of the routing process. For this

purpose, we decompose the global optimization problem by means of a distributed version of the Benders decomposition method. Using this method, the initial optimization problem subdivides into a distributed master problem solved at each node and several subproblems of tractable size involving only local decisions when nodes compute routing path(s) online.

Keywords: Distributed routing, Network design, Benders decomposition.

3 - Time-dependent combined network design and routing optimization

Bernard Fortz, *Université Libre de Bruxelles*, bernard.fortz@ulb.ac.be
Co-author(s): Dimitri Papadimitriou (dimitri.papadimitriou@alcatel-lucent.com), Alcatel-Lucent.

In today's communication networks, distributed control functions such as routing inherit design driven by processing capacity and memory consumption. Henceforth, the routing protocol decision process (distributed and online) remains still decoupled from the routing optimization process (centralized and offline). Distributed optimization does not take into account the distributed nature of the online routing decision making process because distributed optimization is not decomposed along the same dimensions as the routing decision making process. The challenge becomes thus how to modify the outing decision process to include optimization objectives and how to make the optimization problem aware of the distributed nature of the online routing decision process under dynamic conditions. As a first evolution in that direction, we propose a new combined optimization model that integrates network design decisions and routing decisions, with time-dependent demands. As part of our main contribution, the proposed model keeps in sight the need for a distributed routing function,through the use of scalable routing tables. We also put our work in the perspective of a fully distributed, decomposed optimization setting.

Keywords: Network design, network routing, decomposition.

SC-II

15:15 - 16:30
Room: Miguel Ângelo II

Robust optimization I

chair: Adam Ouorou

1 - Robust Optimization for the Connected Facility Location Problem

S. Raghavan, *Smith School of Business, University of Maryland*, raghavan@umd.edu
Co-author(s): M. Gisela Bardossy (mbardossy@ubalt.edu), Merrick School of Business, University of Baltimore.

In this paper we present an Approximate Robust Optimization (ARO) model for the Connected Facility Location (ConFL) problem within the framework introduced by Bertsimas and Sim (2003) and show how to use a heuristic and a lower bounding mechanism to rapidly find high-quality solutions. The use of a heuristic and a lower bounding mechanism—as opposed to solving the robust optimization (RO) problem exactly—within this RO approach significantly decreases its computational time. This enables the solution of large-scale robust optimization problems and broadens the scope and applicability of robust optimization

from a computational perspective to other NP-hard problems. Our computational results attest to the efficacy of the approach, particularly on the Robust ConFL problem, where the computational time is reduced by at least three orders of magnitude (compared to solving the RO problem exactly) while the solutions are on average within 3% from optimality.

2 - Multipolar Routing

Walid Ben-Ameur, *Samovar, Telecom SudParis, France*, walid.benameur@telecom-sudparis.eu

Co-author(s): Mateusz Żotkiewicz (mzotkiew@tele.pw.edu.pl), WUT, Poland.

Assuming that the traffic matrix belongs to a polytope, we describe a new routing paradigm where each traffic matrix is routed using a combination of a number of extreme routings. This combination depends on the current traffic matrix. Multipolar routing can be seen as a generalization of both dynamic routing and robust static routing. Moreover, the complexity of multipolar routing is under control since it depends on the number of poles (*i.e.*, the number of extreme routings) which can be defined by the network planner. Both a centralized and a distributed version of multipolar routing are presented. Numerical experiments show that distributed multipolar can be much more efficient than static routing.

Keywords: Robust routing.

3 - The robust network loading problem with static routing

Sara Mattia, *IASI-CNR* , sara.mattia@iasi.cnr.it

In this paper we address the problem of dimensioning the capacities on the edges of a network to allow the routing of uncertain demands. We show how to derive a capacity formulation for the problem with static routing. We present separation routines to be used within a branch-and-cut algorithm and computational results.

Keywords: Robust Network Design, Static Routing.

SC-III

15:15 - 16:30

Room: Miguel Ângelo III

Survivability networks I

chair: Abdullah Konak

1 - ILP formulations for a Steiner multi-ring network design problem with revenues

Ana Bautzer, *ISCAL- CIO*, aapedro@iscal.ipl.pt

Co-author(s): {Luís Gouveia (legouveia@fc.ul.pt), Ana Paias (ampaias@fc.ul.pt)}, DEIO-CIO; José Manuel Pires (jmpires@iscal.ipl.pt), ISCAL-CIO.

We address the Steiner multi-ring network design problem with revenues which arises in the design of metropolitan optical networks. The SmRNDP consists of designing m capacitated node-disjoint rings that pass through a "hub" and through all the costumers with high priority of service and some of the costumers with low priority of service. The number of customers in each ring has an upper bound (capacity). Besides the usual arc link costs, we

also consider revenues between each pair of costumers in the same ring, even when they are not connect by a direct link. The objective is to minimize the difference between the total connection cost and total revenue. We introduce and discuss four types of integer linear programming formulations and propose some valid inequalities to strengthen the linear programming relaxation. Computational results are presented in order to evaluate the quality of the linear programming relaxation bounds associated to the proposed formulations.

Keywords: Network design; integer linear formulations, linear relaxation, valid inequalities.

2 - Lexicographical Minimization of Routing Hops in Hop-Constrained Node Survivable Networks

Pedro Patrício, *CIO and UBI*, pedrofp@ubi.pt

Co-author(s): Luís Gouveia (legouveia@fc.ul.pt), CIO and FCUL; Amaro de Sousa (asou@ua.pt), IT and DETI.

Given a telecommunications network with known link capacities and a set of commodities with known demands, each of which is supported by D hop-constrained node-disjoint service and backup paths such that total demand protection is ensured in case of both single and double failure scenarios, in this work we address the following traffic engineering problems: how to route small deterministic changes of the original demands, maintaining network survivability and QoS, while minimizing the number of hops in a lexicographical sense of either i) all service paths or ii) the worst service path for each commodity. We present and discuss three classes of Integer Linear Programming models - disaggregated, mixed and aggregated - for both variants of the problem and also present computational results considering D=2, 3, 4 and several traffic demand settings. Additionally, we study the impact of using the lexicographical minimization criteria on the average and maximum delay of the corresponding optimal solutions, by comparing these solutions with the ones obtained in a previous work where the average and maximum delay minimization criteria were specifically used.

Keywords: Hop Constraints, Survivability, Traffic Engineering, Lexicographical Minimization.

3 - Two-Edge Disjoint Survivable Network Design Problem with Relays: A Hybrid Genetic Algorithm and Lagrangian Heuristic Approach

Abdullah Konak, *Penn State Berks*, auk3@psu.edu

This paper presents a network design problem with relays considering the two-edge network connectivity. The problem arises in telecommunications and logistic networks where a constraint is imposed on the distance that a commodity can travel on a route without being processed by a relay, and the survivability of the network is critical in case of a component failure. The network design problem involves selecting two edge-disjoint paths between source and destination node pairs and determining the location of relays to minimize the network design cost. The formulated problem is solved by a hybrid approach of a genetic algorithm (GA) and a Lagrangian heuristic such that the GA searches for two-edge disjoint paths for each commodity, and the Lagrangian heuristic is used to determine relays on these paths. The performance of the proposed hybrid approach is compared to the previous approaches from the literature with promising results.

Keywords: Network Design, Network Survivability, Relays, Genetic Algorithms.

SD-I

16:50 - 18:30

Room: Miguel Ângelo I

Traffic engineering

chair: Stefano Coniglio

1 - Contribution to Modeling and Maximizing Processing in a Network of Telecommunication

Souad Ezzbady, *Department of Mathematics and Computer Science, University Hassan II, Mohammedia, BP 7955, Sidi Othman, Casablanca, Morocco*, souadezzbady@gmail.com

Co-author(s): Namir Abdlwahad (a.namir@yahoo.fr), Department of Mathematics and Computer Science, University Hassan II, Mohammedia, BP 7955, Sidi Othman, Casablanca, Morocco.

The computer networks are based on the Internet protocol conceived from the origin to transport data in more heterogeneous usage (telephony IP, video at request, distributed interactive games, telemedicine, video-conference and audio). These information fluxes or these services before being treated are classified, organized and stocked according to priority rules in different waiting files. To maximize the treatment of these data, we offer in this work a simple and practical step for modeling and implementing information scheduling in the bandwidth. This step respects the priority rules and eliminates in priori any form of wasting of time at the level of service. It consists of maximizing the use of the bandwidth for different types of traffic in a telecommunication network. The proposed algorithm consists of serving the traffics that have priorities and to exploit dynamically what remains of the bandwidth in the profile of the least priority traffics while respecting at the very least the part of every traffic in the bandwidth. The problem is mathematically modeled by an integer linear program (ILP) and in continuation resolute theoretically in general case and numerically in case priority at the level of services. At the end, practical examples to illustrate work are given.

Keywords: ILP (integer linear program), Modeling; Network; Optimization, Processing, QoS.

2 - On Fuzzy Logic Based Decision Making for Dynamically Adaptive Bandwidth Allocation

Jūlija Asmuss, *Riga Technical University* , julija.asmuss@rtu.lv

Co-author(s): Gunars Lauks (gunars.lauks@rtu.lv), Riga Technical University.

We demonstrate how the fuzzy logic overcomes the mathematical complexity of the bandwidth resource allocation problem for multiple traffic classes with different performance objectives in a dynamically changing network environment. Our focus in this talk is decision making on bandwidth resource reallocation taking into account traffic characteristics and behaviour of the system during the previous monitoring period. We present a special algorithm, which works with fuzzy terms and fuzzy operations accordingly to the fuzzification and defuzzification principles and makes decisions based on fuzzy rules and fuzzy inference techniques. The performance of this algorithm is evaluated using simulated decision analysis based on synthesized input data and expert knowledge database of fuzzy rules. We illustrate the effectiveness of the proposed technique by simulation experiments for two traffic classes

(delay sensitive and throughput sensitive) with the subsequent analysis of main QoS characteristics. Finally we discuss the future research on adaptive modification of fuzzy interface membership functions and fuzzy rules to attain optimal decision making under uncertain network conditions.

Keywords: Bandwidth allocation, Traffic control, Fuzzy rule, Fuzzy inference system, Simulation.

Acknowledgement: The support of the following ESF project is kindly announced 2013/0024/1DP/1.1.1.2.0/13/APIA/VIAA/045.

3 - Modelling the steering of international roaming traffic problem

Carlos Martins, *CEMAPRE and ISEG, Universidade de Lisboa, Portugal*, carlos.jl.martins@gmail.com

Co-author(s): Margarida Vaz Pato (mpato@iseg.utl.pt), CIO and ISEG, UL.

Telecom operators establish international roaming agreements with operators from other countries so as to provide service to customers outside their home country. The home operator faces the decision of how much traffic to steer to the network of each international operator in order to minimize its costs. The complexity of decision arises from the coexistence of different types of commercial agreements, the interdependency of traffic sent to different countries and the high number of agreements to be managed. Integer Programming models with integer and binary variables, linear and non-linear constraints, linear and non-linear objective functions, depending on the type of agreement, were developed. The problem may be interpreted as a flow problem over a network where nodes represent countries, (groups of) operators and commercial agreements volume-price tiers. Arcs represent admissible relations; some have costs and bounds on capacities. The problem then becomes the minimization of the cost of the flow (roaming traffic) from the source - the home operator - to an artificial sink node. Small test instances of three of the models, in their network flow version, were solved using Microsoft Excel Solver. Results are presented and discussed.

Keywords: International roaming, traffic steering, integer programming, network flow models.

4 - Bilevel optimization models for traffic engineering with elastic demands and fair flow allocation

Stefano Coniglio, *Lehrstuhl II fur Mathematik, RWTH Aachen University, Aachen, Germany*, coniglio@math2.rwth-aachen.de

Co-author(s): {Antonio Capone (antonio.capone@polimi.it), Luca Gianoli (luca.gianoli@polimi.it)}, DEIB, Politecnico di Milano, Italy; Edoardo Amaldi (edoardo.amaldi@polimi.it), DEIB, Politecnico di Milano, Italy

In classical Traffic Engineering approaches the demands are often assumed to be characterized by a fixed transmission rate known a priori. Although this is appropriate for inelastic demands, it fails to apply to elastic demands, whose rates depend on the distributed control mechanisms (*e.g.*, TCP) which aim at allocating flows so as to fairly exploit the available resources. To account for elastic demands, we address a bilevel optimization problem where (at the upper level) the network operator has to select a single routing path for each demand so as to maximize a utility function (*e.g.*, throughput) and (at the lower level) the rate of each elastic flow is determined by the transport protocol. We consider both Max-Min Fairness and Proportional Fairness principles, which are two reference models to approximate

the flow allocation induced by TCP for a set of elastic demands over a given set of routing paths. We present exact and approximate MILP formulations for this bilevel problem with both types of flow allocation, report some computational results and compare them with those provided by restricted path formulations.

Keywords: Bilevel optimization, traffic engineering, elastic demand, max-min fairness, proportional fairness.

SD-II

16:50 - 18:30
Room: Miguel Ângelo II

Network trees I

chair: S. Raghavan

1 - Spanning Trees with variable degree bounds

Pedro Moura, *CIO - Faculdade de Ciências da Universidade de Lisboa*, pmmoura@fc.ul.pt

Co-author(s): Luís Gouveia (legouveia@fc.ul.pt), CIO - Faculdade de Ciências da Universidade de Lisboa; Amaro de Sousa (asou@ua.pt), Instituto de Telecomunicações, Universidade de Aveiro, Aveiro, Portugal; Mario Ruthmair (ruthmair@ads.tuwien.ac.at), Institute of Computer Graphics and Algorithms, Vienna University of Technology, Vienna, Austria.

We introduce and study a generalization of the degree constrained minimum spanning tree problem where we may install one of several available transmission systems, each with a different cost value, in each edge. The degree of the endnodes of each edge depends on the system installed on the edge. We also discuss a particular case that arises in the design of wireless mesh networks. In this variant the degree of the endnodes of each edge depend on the transmission system installed on it as well as on the length of the edge. We propose three classes of models using different sets of variables and compare from a theoretical perspective as well as from a computational point of view, the models and the corresponding linear programming relaxations. The computational results show that some of the proposed models are able to solve to optimality instances with 100 nodes and different scenarios.

Keywords: OR in telecommunications networks, spanning tree, degree constraints, wireless mesh networks, transmission systems.

2 - Inference of a routing network topology

Cristina Requejo, *Universidade de Aveiro*, crequejo@ua.pt

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The Internet is a collection of interconnected networks, whose topology is unknown because of its decentralized and unregulated growth. Since one cannot count on the cooperation of all the internal network devices, the ideal is to infer the network topology using only end-to-end network measurements, such as loss measurements or delay variance. With this limited information only the logical topology can be inferred. The logical topology is obtained from the physical topology, representing only the physical devices on the network where traffic branching occurs and joining all the connections between these devices by a single

logical link. We present mixed-integer linear programming models to reconstruct a network routing topology using only measurements between each pair of receivers. Local heuristic techniques together with LP solutions are used to accelerate the finding of feasible solutions. Extensive computational results show that the process is quite effective in finding integer feasible solutions, present small gap values, and solve higher size instances.

Keywords: Routing tree, Topology Discovery, Communication network.

3 - Design of networks with unicyclic connected components

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To provide survivability, we build a minimum cost network where each connected component contains exactly one cycle. First, we prove that this problem is easy to solve. Then, we add a new technical constraint related to the size of cycles: the solution should not contain cycles of length less than a certain bound. This constraint makes the problem difficult. A polyhedral study is proposed. Many facets and valid inequalities are derived. Some of them can be exactly separated in polynomial time. Hence the network design problem is solved by a cutting plane algorithm based on these inequalities and using a compact formulation derived from the transversality of the bicircular matroid. We also consider another important variation of the problem. Some given special nodes must belong to cycles. We still want the connected components to be unicyclic while the cycle size constraint is ignored. We show that this problem is a generalization of the perfect binary 2-matching problem. It turns out that the problem is easy to solve. An exact extended linear formulation is provided. We also present a partial description of the convex hull of the incidence vectors of these Steiner networks. Polynomial time separation algorithms are described. One of them is a generalization of the Padberg-Rao algorithm to separate blossom inequalities.

Keywords: Network design, combinatorial optimization.

4 - Local Search for the Reload Cost Spanning Tree Problem

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We discuss the reload cost spanning tree problem (RCSTP) where we try to find the spanning tree with the minimum total reload cost, each node has a demand from every other node, each edge is colored and a reload cost is incurred for every color change. The RCSTP was introduced and shown to be NP-complete by Gamvros et al. (2012). We propose local search heuristics operating in a tree-nontree edge swap neighborhood and how to efficiently conduct search. We present computational results comparing the heuristic solutions with optimal solutions and examine performance for large-scale instances.

SD-III

16:50 - 18:30
Room: Miguel Ângelo III

Optical transport networks

chair: Amaro de Sousa

1 - Design of Optical Transport Networks: the Combined Traffic Grooming, Routing and Wavelength Assignment Problem

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The design optimization of an Optical Transport Network (OTN) is a combination of three optimization problems: the grooming of client demands into a smaller set of lightpaths, the routing of the lightpaths on the underlying fiber network and the assignment of wavelengths to lightpaths on the fiber links of their routing paths (ensuring the wavelength non-overlapping and continuity constraints). In fact, the combination of the two last problems (without the grooming problem), known as the Routing and Wavelength Assignment (RWA) problem, has been proved to be NP-hard. Therefore, up to now, the research has been more directed to approximate methods to tackle relevant sized problem instances. In this presentation, we propose some alternative Integer Linear Programming (ILP) formulations that define the complete network design problem for some network design variants that are of interest in OTNs. We present also additional constraints that strengthen the formulations. Finally, we present some computational results showing that the addressed variants can obtain either provable integer optimal solutions or, at least, integer solutions with small optimality gaps for problem instances of relevant size within runtimes of 2 hours.

Keywords: Network Design, ILP formulations, Optical Transport Networks.

2 - Branch-and-Cut algorithm for the Optical Multi-Band Network Design problem

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A major challenge for nowadays telecommunication actors is to propose solutions to ensure a smart use of network resources. This can be possible by using the multi-band Orthogonal Frequency Division Multiplexing technology for optical transmissions. We address the problem of designing an optical network using this technology. Given an optical fibre layer, a set of traffic demands and a set of facilities, called subbands. We wish to determine a minimum cost assignment of the demands to the subbands, so that every demand is routed and each used subband is associated with a path in the fibre layer. We will refer to this problem as the Optical Multi-Band Network Design problem. We propose here an integer linear programming formulation for the problem and wee study the associated polyhedron. We then derive new classes of valid inequalities and investigate their facial structure. Based on the provided polyhedral results, we devise a Branch-and-Cut algorithm. We then carry on an experimental study to give an insight of the effectiveness of our approach. We show a set of

computational results for random and realistic instances. Finally, we manage to solve the problem for real networks and traffic matrices, provided by the french telecommunication operator Orange.

Keywords: Optical multi-band networks, network design, polytope, facet, Branch-and-Cut algorithm.

3 - An exact algorithm for spectral assignment in flexible WDM grid optical networks

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We address the interval coloring (aka spectral coloring) problem, which arises in the planning of modern flexible WDM grid networks. Given a set of fixed paths with integer demands, the task is to assign to each path an interval of length equal to the path's demand such that intervals that correspond to paths sharing an edge are disjoint. The objective considered in this talk is to minimize the span needed to accommodate all intervals. We present an exact algorithm based on branch-and-price that is working in two stages. In the first stage, we solve an ILP formulation of a multi-coloring relaxation and employ several heuristics to quickly generate good solutions and bounds. If this stage fails to prove optimality, we run a branch-and-price algorithm based on an exact ILP formulation for interval coloring in the second stage. This two stage approach proves to be computationally efficient in our experiments, solving realistic instances with up to 1000 paths within seconds.

Keywords: Interval coloring, flexible WDM, spectral assignment, branch-and-price.

4 - The Routing and Wavelength Assignment Problem in the Optical Transport Networks Design

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Optical Transport Networks (OTNs) use DWDM to carry traffic through optical networks. A lightpath is an all-optical DWDM channel that may cross multiple fibers. The routing and wavelength assignment (RWA) problem aims to route all lightpaths while ensuring that no lightpath uses the same wavelength as another in the same fiber. The wavelength conversion requires regenerators. Otherwise, lightpaths must use the same wavelength along all fibers of their route. We deal with the RWA problem characterized as follows: (i) we must route and assign wavelengths for a given set of lightpaths, (ii) we allow regenerators to be placed only on intermediate nodes, (iii) we consider lightpath maximum length constraints and (iv) we consider the cost of a solution as the sum of the lightpath endnode costs and regenerator costs. We propose different compact ILP models for two OTN design problem variants. In the first variant, we aim to minimize the solution cost. In the second variant, among all minimum cost solutions, we aim to minimize the maximum assigned wavelength. We present computational results, where the proposed models are solved through CPLEX, which show that provable optimal solutions can be computed for relevant sized problem instances within reasonable runtimes.

Keywords: Network Design, ILP Models, Optical Transport Networks, Routing and Wavelength Assignment.

Monday

MA-I

9:00 - 10:15
Room: Miguel Ângelo I

Multicommodity network routing

chair: Eli Olinick

1 - New Results on Multipath Routing

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Multipath routing of traffic demands, known also as bifurcated routing or load sharing, has been studied for various telecommunication networks for a long time. An advantage of multipath routing is that it gives a demand the opportunity to use multiple paths through the network to send its traffic. In a single-commodity situation, this benefit can be clearly seen. When multiple demands (multi-commodity situation) compete for the same resources in a network, we focus on the problem of how many demands can take real advantage of multiple paths. In this context, we present new results on multipath routing for a number of network traffic objectives. We show that under certain traffic conditions and topological structures, multipath routing provides virtually no gain compared to single-path routing when the traffic is offered for all demand pairs in a network. We also present results on how different network objectives influence the ability of taking advantage of multipath routing. Our results, based on the basic properties of linear programming, are somewhat against a rather common belief (expressed by the term "load sharing") that multipath routing is significantly more effective in carrying traffic than single-path routing.

Keywords: multipath routing, load sharing, traffic efficiency, linear programming.

Acknowledgement: The work of the US authors was supported in part by NSF Grant No. CNS.0916505. The work of M. Pioro was supported by National Science Center (Poland) under Grant No. 2011/01/B/02967.

2 - Efficient algorithms for the maximum concurrent flow problem

Walid Ben-Ameur, *Samovar, Telecom SudParis, France*, walid.benameur@telecom-sudparis.eu

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We study some decomposition algorithms to solve the maximum concurrent flow problem. We first consider the tree model where the flows of commodities sharing a same source node are routed on a set of trees. Compared to both classical path formulation and aggregated arc-flow formulation, the tree-based linear programming formulation can be solved much more quickly. Then we propose a generic aggregation scheme leading to different formulations. Some of them can even be better than the tree formulation. The pricing problem corresponding to the generic model is based on shortest-path computations. Finally, we

focus on the single-source case. A strongly polynomial-time combinatorial algorithm is proposed and implemented for this special case.

Keywords: Multiflow problem, column generation, combinatorial algorithm.

3 - Empirical Analysis of a Compact Formulation of the Network Design Problem

Eli Olinick, *Southern Methodist University*, olinick@smu.edu

Network flow problems are most naturally characterized by the edge-path formulation where all paths may have assigned flows and each edge constrains the total flow assigned to all paths traversing that edge. This model suffers from having an LP formulation that grows exponentially with problem size. The equivalent node-edge formulation is a multicommodity flow formulation where, for bookkeeping purposes, each node (vertex) designates a distinct commodity yielding a polynomially bounded LP formulation. The artificial distinction of separate commodity flows is unnecessary for many applications. We present a new formulation for network flows in undirected graphs that yields LP's that are significantly smaller than those derived from the node-edge or edge-path formulations. This characterization of network flow yields a more compact formulation allowing more efficient solutions including instances either too large or too time consuming to solve by the standard edge-path and node-edge formulations. Previously we found that CPLEX typically solves the maximum concurrent flow problem two to four times faster with our formulation than with the node-edge formulation when available computer memory allows both to be solved. Here we present an empirical study comparing our new, compact formulation of the network design problem to the classical node-edge and edge-path formulations.

Keywords: Network design, linear programming, multicommodity flow, routing in networks.

MA-II

9:00 - 10:15
Room: Miguel Ângelo II

Security and emergency

chair: Sadan Kulturel-Konak

1 - A Location Privacy Preserving scheme for Routing in MANET Using Rough Sets

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In Mobile Ad hoc Networks, a source relies on intermediate nodes to transfer data packets to a destination. However, the malicious intermediate nodes can track location of source and destination, and also trace the routes taken by the packets, thus resulting in a location privacy breach. Providing location privacy for nodes is essential to minimize the attacks. Earlier works on maintaining location privacy, rely on changing node identity or masking of the location information by adding noise, resulting in high cost and service quality degradation. In this paper, we propose a novel Location Privacy preserving scheme for Routing in Mobile Ad hoc Networks using Rough Sets. The scheme establishes a route, which maintains source and destination nodes location privacy, and provides an untraceable route by using

rough sets to define trust attributes for the neighbor nodes. In each routing step, source node selects the most trusted 1-hop neighbor node and forwards the data packet to it. The selected trusted neighbor node acts as a temporary source and forwards the data packet to its trusted 1-hop neighbor node. These steps are continued till the destination node is reached. The effectiveness of our scheme is shown by simulation results.

Keywords: Mobile Ad hoc Network, Location Privacy, Trust, Rough Sets, Route Untraceability.

2 - An Optimization Model for Portable Base Stations in Disaster Planning and Management

Michael Bartolacci, *Penn State University - Berks*, mrb24@psu.edu

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Disaster response requires communications among all affected parties including emergency responders and the affected populace. Wireless telecommunications, if available through a fixed structure cellular mobile network, satellites, portable station mobile networks and ad hoc mobile networks, can provide this means for such communications. While the deployment of temporary mobile networks and other wireless equipment following disasters has been successfully accomplished by governmental agencies and mobile network providers following previous disasters, there appears to be little optimization effort involved with respect to maximizing key performance measures of the deployment or minimizing overall cost to deploy. This work-in-progress does not focus on the question of what entity will operate the portable base during a disaster, but on optimizing the placement of mobile base stations or similar network nodes for planning and real time management purposes. An optimization model is proposed for the staging and placement of portable base stations to support disaster relief efforts.

Keywords: Portable Base Stations, Disaster Planning.

3 - A Bi-level Genetic Algorithm Approach for the Network Server Assignment Problem

Sadan Kulturel-Konak, *Penn State Berks*, sxk70@psu.edu

Successful operations of telecommunication networks require an uninterrupted availability of critical network services. This paper addresses the problem of server assignment in telecommunication networks to maximize the availability of critical services under the presence of attacks. The problem is formulated as a bi-level optimization problem with two decision makers, the network designer and the attacker. The network designer's objective is to maximize the availability of network services by determining the best set of nodes in which services are deployed. The attacker decision's problem is to determine an attack strategy that results in the maximum service disruption. It is assumed that the network designer is not aware of the attacker's strategy. On the other hand, the attacker has the knowledge of the network designer's decision. A bi-level genetic algorithm is presented to solve the server assignment problem in telecommunication networks, and the convergence property of the proposed algorithm is discussed.

Keywords: Server assignment, bi-level optimization, genetic algorithm, network resilience.

MB-I

10:30 - 12:10

Room: Miguel Ângelo I

Network trees II

chair: Maurício Resende

1 - Optimal capacitated ring trees

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We study a new network design model combining ring and tree structures under capacity constraints. The solution topology of this capacitated ring tree problem is based on ring trees which are the union of trees and 1-trees. The objective is the minimization of edge costs but could also incorporate other types of measures. This overall problem generalizes prominent capacitated vehicle routing problems and Steiner tree problem variants. Two customer types have to be connected to a depot ensuring single and double node connectivity, respectively, while installing optional Steiner nodes. The number of ring trees and the number of customers supplied by such a single structure are bounded. After embedding this combinatorial optimization model in existing survivable network design concepts, we elaborate two mathematical formulations and develop corresponding exact algorithms. Additionally, we present a heuristic using local search on sophisticated neighborhoods that we also integrate as a subprocedure. For a set of literature-derived instances we consider various reliability scenarios and present computational results.

Keywords: Capacitated ring tree problem, Steiner tree, vehicle routing, survivable network design, integer programming.

2 - Packing and Scheduling of Steiner Trees for Data Synchronization

Eric Gourdin, *Orange Labs, France*, eric.gourdin@orange.com

Modern telecommunication networks are essentially used to access ever growing amounts of data. To increase performance and robustness, these data are replicated and distributed along many storage servers. One of the major concern when managing distributed storage systems is to ensure that all the copies are identical, even when the original data or one copy has been modified. It is hence necessary to design efficient subnetworks interconnecting the various servers and orchestrate the synchronization sessions within the limited resources offered by the underlying transport networks. We consider a problem where the synchronization sessions must be carried and schedules over multicast trees. This problem can be formulated as a combination of a bin packing problem and several Steiner tree packing problems. We propose several mixed-integer formulations for this problem and a decomposition scheme. Some preliminary results are reported.

Keywords: Steiner tree packing, data synchronization.

3 - Models for traffic engineering with multiple spanning tree protocols

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The Multiple Spanning Tree Protocol used in Ethernet networks, maintains a set of spanning trees that are used for routing the demands in the network. Each spanning tree is allocated to a pre-defined set of demands. We have developed two mixed integer programming models for the Traffic Engineering problem of optimally designing a network implementing the Multiple Spanning Tree Protocol, such that link utilization is minimized. We present tests in order to compare the two formulations, in terms of formulation strength and computing time. We also propose a binary search algorithm that has proven to be efficient in obtaining quasi-optimal solutions for this problem.

Keywords: Telecommunications; traffic engineering; multiple spanning tree protocol; mixed-integer programming.

4 - A biased random-key genetic algorithm for a prize-collecting directed Steiner forest network design problem

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We model a wireless backhaul network design problem as a prize-collecting directed Steiner forest problem. In this problem we are given a set of demand points where wireless traffic originates, along with the amount of traffic, a set of backbone access points, and we want to build a wireless backhaul network to transport the traffic from the demand points to the backbone by using equipment installed on a set of given utility poles. LTE and Wi-Fi are used to capture traffic from demand points and backhaul transmission equipment is used to transmit traffic between utility poles and between utility poles and backbone access points. There are many types of constraints imposed on the design, e.g., maximum transmission equipment coverage, maximum number of hops from the demand point to the backbone node, maximum node in-degree, and link capacity on the sum of flow into a node and the traffic captured by the LTE and Wi-Fi equipment at the node. The objective is to maximize the difference between the monetary value of the backhauled traffic and the cost of building and operating the network. We present a biased random-key genetic algorithm to solve this problem.

Keywords: Networks; design; wireless backhaul; heuristics.

MB-II

10:30 - 12:10

Room: Miguel Ângelo II

Optical access networks

chair: Axel Werner

1 - Large-scale FTTH network design

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We present an optimization platform for FTTH network design. The platform is capable of minimizing CAPEX of network deployment by optimizing locations of: OLTs, splitters, and cabinets. Moreover, it calculates a number and type of PON cards to be used in each OLT. It also optimizes routes, types of cables, utilized splitters, and PON card ports for each demand. The platform takes into account: attenuation of cables, splitters, and optical plugs; power budget for each demand; output power of each PON card type; available telecommunication infrastructure; costs of splicing fibers and trenching; effect of scale while rolling out cables, etc. The platform aims at facilitating large deployment projects with up to 100k access points. Considered networks consist of up to 200k nodes making a use of non-exact approaches a must. The methodology implemented in the platform ranges from distributed local search methods and fast evaluation algorithms in the early stages of the optimization process to modular MIP models for polishing a solution. In the presentation we introduce an architecture of the platform and algorithms it implements.

Keywords: FTTH, access networks.

Acknowledgement: The presented work was supported by the Ministry of Science and Higher Education (Poland) under grant IP2012 065372.

2 - Single PON network design with unconstrained splitting stages

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A Passive Optical Network (PON) is a network technology for deploying access networks based on passive optical components. In a single PON access network, the client terminals are connected to a Central Office through optical splitters and interconnecting fibers where each splitter splits the input optical signal coming from the Central Office over its different output ports. In this paper, we consider a PON topology where the splitting ratio and the number of splitting stages is not constrained to a given target design but, instead, are decided based on the cost of the network solution. We present different Integer Linear Programming formulations to model this problem and provide computational results showing that the optimal solutions can be computed for realistic problem instances. In addition, we show how the formulations can be adapted for the traditional PON topology approaches and present computational results showing that significant cost gains can be obtained with the unconstrained splitting stage approach.

Keywords: OR in telecommunications, Network design, Integer linear programming, Passive optical networks.

3 - A Local Search Approach to Finding Distance-Constrained Disjoint Paths in Long-Reach Passive Optical Networks

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Long-Reach Passive Optical Networks (LR-PONs) are gaining increasing interest as they provide an economically viable solution for fibre-to-the-home network architectures. A major fault occurrence in LR-PON would be a complete failure of the metro-node, which could affect tens of thousands of customers. The dual homing protection mechanism for LR-PON enables customers to be connected to two metro-nodes, so that whenever a single metro-node fails all customers are still connected to a back-up. The cost of deploying such a network is mainly influenced by the amount of cable used. Therefore, the objective is to minimize the amount of cable used while ensuring disjointness. We present a efficient local search approach to finding two edge disjoint routes for all exchange-sites to their respective metro-nodes. The approach can easily scale for LR-PONs containing 10,000 exchange-sites. The developed approach is generic and can be used in other networking problems that exhibit tree-like structures. The effectiveness our approach is demonstrated by presenting results for Ireland, UK, and Italy datasets. Our LS approach provides us with good quality solution quickly, which is important in the design process of optical networks since the user can quickly test the specification of the problem and adapt the constraints accordingly.

Keywords: Network Resilience, Local Search, LR-PON, Optimization, Disjoint Paths.

4 - Multicriteria optimization for optical access network planning

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In the planning of fiber optic access networks (FTTx networks), decisions usually involve quite large amounts of money. Cutting on costs, however, leads to disadvantages, such as lower coverage rates, worse quality of service, or higher operational costs. Hence, FTTx network planning is naturally a multicriteria optimization task. We introduce and discuss variants of the Biobjective k-Architecture Connected Facility Location Problem, which can be used to model various planning situations that arise in this context, as well as extensions to multiobjective problem variants. We also address different solution methods that can be applied to these models and report on some computational tests.

Keywords: Multicriteria Optimization, FTTx networks, Connected Facility Location.

MC-I

14:00 - 15:40
Room: Miguel Ângelo I

Reliability networks

chair: Stefan Voß

1 - Topological optimization of reliable networks under failure correlation

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Topological optimization of reliable networks is a problem that has been deeply studied. This problem looks for the optimal topology of a network that maximize the reliability subject to a budget constraint. Since even the computation of the reliability of a network is an NP-hard problem, proposed solutions to this problem are based on meta-heuristics or sampled approximations. However, most of these studies assume independence among the link failures. Recent literature shows empirically that correlations between failures are significant. In this work, we compare the impact of failure correlations in the optimal topological design of a network. We use copula-based failure models, which allow us to incorporate explicitly a correlation matrix between failures. Using this failure model, we show that correlation can change the optimal solution drastically. We also propose a sample-average-approximation integer programming model to solve this problem incorporating the correlation of failures.

Keywords: Reliability, Topological Optimization, Failure Correlation, Sampled Average Approximation.

2 - Performability Analysis of a Metro Area Cellular Network

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We describe a model and associated metrics for evaluating the performability (performance + reliability) of a metro area network. The model extends over both the "wireline" backhaul and wireless portions of the network, i.e. from the mobile telephony serving office (MTSO) to the users of wireless devices. The model captures potential outages in the backhaul, such as switches, network access and termination devices, uncertainty in fiber routing, and base station equipment in the radio access part. It includes effects of potential path loss, interference, and traffic variability in the radio access, and also represents the migration of wireless users among macrocells in response to potential outages in the overall network. The last part of the model represents a population of (stationary) wireless users randomly distributed in a geographical area, but with density in accordance with measured base station traffic. The model is analyzed with the "most probable state" method for performability evaluation to compute approximate probability distributions for metrics such as cell site disconnection due to potential outages in the backhaul, link utilizations in the backhaul, loss of coverage for wireless users, and a "service acceptability" metric. The results are useful for assessing the cost vs. performance of the network design.

Keywords: Network, performability, wired, wireless.

3 - Integer models for diameter-bounded clusters resilient to a link failure

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Graph structures are powerful tools to analyse relational data in sociology, marketing, and telecommunications networks studies. Relational data is not concerned with the properties of a single element but with the connections through which the elements relate to one another. In many cases, one of the goals of the analysis is the identification of clusters in the data files. The properties that define a cluster have to be established according to the nature of the data and the objectives of the study. In this talk, we introduce a new graph structure to represent diameter-bounded clusters resilient to a link failure. For the associated problem of finding the maximum cardinality cluster resilient to a link failure with a diameter bounded from above by a given integer $k > 1$, we propose alternative formulations, stated with different sets of variables. Results of a comparative study of the models for the cases $k = 2$ and $k = 3$ are reported.

Keywords: integer programming; formulations; network reliability.

4 - New Algorithms for the Reliability Redundancy Allocation

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This paper is concerned with the reliability Redundancy Allocation Problem (RAP), whose objective is the optimal allocation of redundant components within a series-parallel system with n different subsystems in series and a number of parallel components within each subsystem. The problem is complicated by the existence of knapsack-type resource constraints, typically describing limitations in terms of volume, weight, and cost. The RAP is motivated by means of reliability requirements in practical applications of telecommunications system design. To achieve reliability one may resume to one or both of two different approaches focusing on adding redundant components and/or increasing the reliability of the individual components. The goal is to maximize the overall system reliability. We work with a discrete-binary transformation of the RAP into its corresponding binary version. Based on this we propose a corridor method and a dynamic programming based implementation to solve the problem. Moreover, we investigate the transformation of the RAP into a multiple choice knapsack problem and provide a branch and cut algorithm. The algorithm is tested on well-known sets of benchmark instances. All instances have been solved to optimality in milliseconds or very few seconds on a normal workstation. This includes the provision of optima, which were previously unknown.

Keywords: Redundancy allocation, reliability, multiple choice knapsack, branch & cut.

MC-II

14:00 - 15:40
Room: Miguel Ângelo II

Economics and mobile applications

chair: Paulo Cordeiro

1 - A Novel Dynamic Pricing Model for the Telecommunications Industry

Kholoud Dorgham, *Faculty of Computers and Information - Cairo University*, k.dorgham@fci-cu.edu.eg

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Telecommunications industry is a highly competitive one where operators strategies usually rely on massively reducing minute rate in order to acquire more subscribers and thus have higher market share. In the last few years, the numbers of customers are noticeably increasing leading to more traffic on different network cells; specifically in highly populated regions. The uneven distribution of traffic and the congestion on some network cells may lead to an increased number of blocked calls i.e. worse quality of service (QoS). An improved pricing system – even by trivial amounts – can lead to enormous increases in profits due to a huge amount of calls at stake in addition to reducing blocked calls. And hence, we propose a dynamic pricing model for the mobile calls based on a Monte-Carlo simulation that emulates the processes of call arrivals, call durations and the effect of price on both. This model is then integrated with a meta-heuristic evolutionary based optimization algorithm to determine the optimal dynamic pricing schemes according to the call parameters. This integrated framework is a novel approach to dynamic pricing that aims at maximizing revenue and enhancing the QoS.

Keywords: Telecommunications, Dynamic Pricing, Optimization, Monte-Carlo Simulation.

2 - Network and economic trade-off performance regions of carrier sense multiple access protocols with cooperative diversity using multi-objective and financial portfolio optimization

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This paper addresses the study of a class of carrier sense multiple access protocols (CSMA) where idle terminals are allowed to relay the signal of other terminals in the network. Unlike previous works, this paper uses multi-objective and financial portfolio optimization tools. Multi-objective optimization allows for an accurate trade-off analysis between different metrics. Financial optimization allows us to consider each transmission as a financial asset whose allocation must optimize economic metrics such as return and risk. Different trade-off performance region are here investigated: the conventional throughput and stability regions, sum-throughput vs. fairness, sum-throughput vs. power, and return vs risk. Fairness is evaluated by means of the Gini index, which is used in the field of economics to measure income inequality. Power consumption is measured as proportional to the transmission rate. It is shown that cooperation allows for an increase of throughput, stability and sum-throughput

vs fairness regions. It also allows for an increase of power consumption with a reduction of overall financial risk in the network. Risk is directly linked to the interference and potential collisions. These results hold in scenarios where a group of users with good channel states and low traffic cooperate with terminals experiencing less favorable conditions.

Keywords: Random access, multi-objective optimization, Pareto optimality, financial portfolio optimization, trade-off analysis.

3 - Models for Video-on-Demand Scheduling with Costs

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Video-on-demand, which provides digital content as needed, supplies flexibility for the users but presents reactive challenges for the provider, as the peaks and troughs in demand lead to an inconsistent requirement of resources. The cost of keeping servers primed for demand that may not appear must be balanced against the cost of frustrating users who must wait for service. This VoD problem is a bi-objective optimization problem, minimizing cost to the provider and delay for the user. First, we introduce an idealized bin packing model that includes the costs of running the servers and servicing users, as well as the cost of acquiring the servers. This uses work of Ahlroth et al. (2013) that involves holding and delay costs for bins that are warehoused before being shipped. Second, mindful of real world applications, we introduce models that allow multiple jobs on each machine, and that account for transient situations, in which many users change demands simultaneously. We build on Azar et al. (2013) who introduce approximation algorithms and prove conditions for optimality for the VoD problem in both clairvoyant and non-clairvoyant settings. We explore the performance of our algorithms and present some preliminary results.

Keywords: Video-on-demand, scheduling, bin packing.

4 - HEVC Video Streaming Decoding Complexity Analysis

Paulo Cordeiro, *ipleiria*, paulo.cordeiro@ipleiria.pt

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Traffic caused by video applications targeting mobile devices and tablet PCs and the transmission needs for video-on-demand services are imposing severe challenges on today's networks. An increased desire for higher quality and better resolutions is also arising among mobile applications. The emerging HEVC video coding standard's purpose is to double coding efficiency with respect to the H.264/AVC high profile. This feature will deliver the same video quality at half of the bit rate. The complexity of the HEVC video decoder's development by the JCT-VC community will be analysed in this paper. In particular, the HEVC reference decoder HM 9.5 will be examined along with Intel Vtune on Intel Core i5. Our study will thusly evaluate both low complexity (LC) and high efficiency (HE) settings for different resolutions up to 1600p (2560×1600 pixels). The results will then be paralleled with the corresponding results of the H.264/AVC baseline profile (BP) and high profile (HiP) reference decoders. Indeed, it will be evident that the decoding complexity of the HE configuration is considerably higher than that of the LC. This is because the

HE is the most complex configuration with regard to function motion compensation (MC) and loop filtering (LF), which account for the majority of the decoder's complexity. Thus, in practice, a standard 3,4 GHz core i5 processor should be able to decode 1080p HEVC streams in real time.

Keywords: HEVC, Complexity, Video coding.

Tuesday

TB-I

10:30 - 12:10
Room: Miguel Ângelo I

Stochastic related problems

chair: Michael Bartolacci

1 - Hop count performance analysis for the furthest and nearest routing protocols in sensor networks

Gonçalo Jacinto, *DMATECT of Évora University and CIMA, Portugal*, gjcj@uevora.pt

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The number of hops between a source and a destination node is an important metric for the design and performance analysis of routing protocols in sensor networks with randomly distributed nodes. However, due to the complexity involved, most of the existing studies in the plane are confined to single link models or to approximation results. In this work we derive closed formulas and establish asymptotic results for the individual hop advancement metrics, such as the hop progress, the hop length and distance to destination under the furthest and the nearest routing protocols. Moreover we derive the probability distribution of the number of hops (hop count) between a source and destination nodes using a novel propagation model for the two routing protocols considered when relay nodes are distributed according to a two-dimensional Poisson process. Resorting to the Poissonification technique the hop count distribution is also obtained when a fixed number of relay nodes are uniformly distributed in the region of interest. Numerical results are obtained to compare the performance of the two routing protocols.

Keywords: Multihop sensor networks, hop count distribution, hop advancement, Poissonification.

2 - Prioritized Limited Round-Robin System with its Performance Analysis

Yoshiaki Shikata, *Shobi-University*, shikata@ictv.ne.jp

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Suppose that there are two classes and that an arriving (class-1 or class-2) request encounters n1 class-1 and n2 class-2 requests in a single-server system. We then propose a new prioritized limited round-robin (RR) rule, under which m quanta are individually and simultaneously allocated to class-1 requests in each RR cycle, whereas one quantum is allocated to class-2 requests, if $m \times n1 + n2 = C$. Otherwise ($m \times n1 + n2 > C$), the arriving request is either queued in the corresponding class waiting room or rejected. Here, m denotes the priority ratio, and C, the service-facility capacity. Our rule expands the Kleinrock's priority PS rule and the limited PS rule into the case of quantum size ¿ 0. Performance measures of practical interest are evaluated via simulation. In the evaluation, the sojourn time of an arriving request is evaluated using the requested service time, number of quanta included in each RR cycle, and quantum size. Then, the change in the number of quanta needed before service is complete is reevaluated at the arrival or departure of other class-1 and class-2

requests. The proposed RR rule and performance evaluation results are realistic in the TSS server and client type communication system.

Keywords: Server and client system, round-robin, loss probability, quantum, sojourn time.

3 - An Inexact Sample Average Approximation Approach for the Stochastic Connected Facility Location Problem

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The sample average approximation (SAA) approach is a widely used technique, based on Monte-Carlo simulation, often applied to large scale stochastic optimization problems. By this approach, a set of sample average problems with multiple copies of sampled scenarios is generated and solved exactly. It is inherently assumed that the sample average problems are solvable to optimality. In some instances, however, the sample average problems, might be NP-hard problems, often impractical to solve to optimality. Consequently, we broaden the scope of the SAA approach and show that, even without solving the sample problems to optimality, by combining a heuristic and a lower bounding approach, tight confidence bounds on the optimal solution value can be obtained. We demonstrate the "inexact SAA approach" on the Stochastic Connected Facility Location (SConFL) problem, which models a family of network design problems with incomplete or uncertain information, with stochastic assignment costs.

4 - Buffer overflow simulation in self-similar queuing networks with finite buffer capacity

Michael Bartolacci, *Penn State University - Berks*, mrb24@psu.edu
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The paper recommends an approach to estimate effectively the probability of buffer overflow in self-similar queuing networks with finite buffer capacity. Simulations with stochastic (or long-range dependent) traffic source models are conducted. A new efficient algorithm, based on the RESTART method, is developed and applied to accelerate the buffer overflow simulation in a finite buffer single server model under long-range dependent self-similar traffic load with different buffer sizes. Numerical examples and simulation results are provided.

Keywords: Long-range dependent processes, self-similar queuing network with finite buffer capacity.

TB-II

10:30 - 12:10

Room: Miguel Ângelo II

Robust optimization II

chair: Sara Mattia

1 - A Robust Optimization Model for Radio Resource Assignment in OFDMA Wireless Networks

Paolo Detti, *Department of Information Engineering and Mathematical Sciences, University of Siena, Italy*, detti@dii.unisi.it

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Orthogonal Frequency Division Multiple Access (OFDMA) has become an important feature of new generation wireless networks, due to its more efficient use of scarce radio resources available for wireless transmissions. In this work, we address the problem of assigning radio resources and transmission formats to users in the downlink of an OFDMA-based network. Specifically, we consider a multi-cell environment with a realistic interference model and a margin adaptive approach, in which the aim is to minimize the total transmission power while maintaining a given transmission rate for each user. Given the intrinsically uncertain behaviour of the wireless channel, that may depend on many unpredictable factors (*e.g.*, weather and conformation of the propagation environment), the gain coefficients representing signal attenuation commonly deviate from the reference values provided by propagation models. To guarantee protection from these deviations, which may compromise the feasibility and quality of the resource assignment, we propose a robust optimization model based on cardinality constrained uncertainty sets - Gamma-robustness (Bertsimas and Sim, 2004) and Multiband Robustness (Büsing and D'Andreagiovanni, 2012). We complete our study by assessing the performance of our approach by computational experiments on realistic network instances.

Keywords: Wireless Networks, OFDMA, Resource Assignment, Mixed Integer Programming, Robust Optimization.

2 - A Hybrid Heuristic for Robust Multiperiod Network Design

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The canonical Capacitated Network Design Problem (CNDP) consists in minimizing the cost of installation of capacity modules in a network to route traffic flows generated by users. In this work, we investigate the Robust Multiperiod Network Design Problem, a generalization of the CNDP which additionally considers a planning horizon with multiple time periods and solutions protected against fluctuations of traffic volume. To ensure protection against

traffic volume uncertainty, we propose a Robust Optimization model based on Multiband Uncertainty (BÃŒsing and D'Andreagiovanni, 2012), a refinement of classical Gamma-robustness (Bertsimas and Sim, 2004) that uses a system of multiple deviation bands. Given the intrinsic difficulty of the problem, which can be hard to solve even for state-of-the-art MIP commercial solvers, we propose a hybrid primal heuristic based on the combination of a randomized fixing strategy, exploiting information coming from linear relaxations of the problem, and an exact large neighbourhood search. Computational experiments on a set of instances from the SNDlib (http://sndlib.zib.de) show that our heuristic can find solutions of extremely good quality associated with low optimality gaps.

Keywords: Multiperiod Capacitated Network Design, Traffic Uncertainty, Robust Optimization, Multiband Uncertainty, Metaheuristic.

3 - Solving a robust network design problem with simple polyhedral demand uncertainties

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We seek to design optimal robust client-server networks: Suppose that we want to transfer a single commodity (e.g., data) among the nodes of a network. Each node has a minimum and a maximum balance limiting how much of the unique commodity the node can supply or demand. Our aim is to find minimum cost integer capacities for the network's links such that all possible realizations of supplies and demands can be routed through the network. This gives us a worst-case robust model with polyhedral uncertainties. Applications for the model lie in networks where all servers can answer the client's requests which is, for instance, true for movie streaming networks. We build on previous work by Buchheim, Liers and Sanità (INOC 2011) and a previous joint work by authors (ISCO 2012) with Álvarez, Dorneth and Parriani to develop a branch-and-cut algorithm for the problem. It uses a capacity based linear program to obtain lower bounds for the objective value and derives upper bounds with problem specific rounding heuristics. To solve the linear program, we give a separation algorithm and tighten our formulation with 3-partition inequalities. Finally, we evaluate the algorithm experimentally.

Keywords: Robust network design, optimization.

4 - Robust models for LP with uncertain right hand side - applications to capacity assignment in telecommunications

Adam Ouorou, *Orange Labs, France.*, adam.ouorou@orange.co

We propose new robust models for handling right hand side uncertainty in linear problems. Upper approximations are constructed using linear decision and zero-order rules on the adjustable variables and an heuristic is proposed to compute lower bounds. Tractable reformulations are given on two uncertainty sets arising in practice. To assess the methodology we consider its application on the capacity assignment problem.

Keywords: Robust Optimization, Capacity assignment, Demand uncertainty.

TC-I

15:15 - 16:30
Room: Miguel Ângelo I

Energy aware routing

chair: Bernardetta Addis

1 - Energy Efficient Routing for Telecommunication Networks with Multi-Period Traffic Demands

Dorabella Santos, *Instituto de Telecomunicações*, dorabella@av.it.pt
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We address the energy efficient routing problem for capacitated telecommunication networks. In this problem, we consider that network links spend a given amount of energy when they are routing traffic demands or are put into a sleep mode (with negligible energy consumption) otherwise. We consider multi-period traffic demands such that each demand is routed through a single path that can change only between time periods. The problem aims to compute a routing path for each demand at each time period with two objectives: minimize the total network energy consumption and minimize the number of demands whose routing paths change between time periods. We propose a multi-thread GRASP based heuristic to solve this bi-objective problem. We present computational results showing that, in most cases, significant energy savings are obtained with a small percentage of demands changing routing paths between time periods. We also address methods to define time periods. We use a set of 288 traffic matrices, measured in 5 minute intervals in a 24 hours period (available in SNDLib) to study the impact on the routing solutions of the different methods. We present computational results showing that near optimal solutions can be found with a small number of time periods.

Keywords: Energy Efficient Routing, Bi-Objective Optimization, Multi-Period Routing, Meta-Heuristics.

2 - Energy efficient network operation with a limited number of network configurations

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Energy consumption has become a major concern for nation-wide telecommunication network operators. Conventionally, network equipment is operated statically even though the traffic volumes to be routed through a network may change considerably over the day. As a measure to cut energy costs, network hardware with flexible operation modes can be used to adapt the network and hence its power consumption to the actual demands. As long as such flexible networks are not yet a well established technology, network operators would likely prefer to choose from a limited number of thoroughly tested configurations for employment at carefully chosen time points instead of freely and incessantly reconfiguring the network. We propose a procedure to obtain a set of reconfiguration time points and associated network configurations aiming at minimizing energy consumption. This is achieved by computing shortest paths through certain graphs where the edges of a path correspond to time intervals in which the configuration does not change. Some constraints on the reconfigurability of

the network, e.g., the maximum number of reconfigurations within the time horizon or the minimum time between reconfigurations, translate to constraints on the graphs or paths.

Keywords: Telecommunication, flexible network design, energy efficiency.

3 - On the Energy Cost of Resiliency in IP Networks

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Despite the growing concern for energy consumption of Internet, green strategies for network and traffic management cannot undermine the quality and the functional level expected from carrier networks. In particular, a very important issue that may be affected by green networking techniques is resilience to node and link failures. We consider the problem of minimizing energy consumption of networks that explicitly guarantee network survivability to failures. Network consumption is reduced by putting in sleep mode idle line cards and nodes according to daily traffic variations that are modeled by dividing a single day into multiple time intervals. To guarantee network survivability we consider two different schemes, dedicated protection and shared protection. Furthermore, we impose some inter-period constraints necessary to guarantee network stability and preserve device lifetime. Both optimization models and heuristics are proposed. Experimentations carried out on realistic networks operated with flow-based routing protocols (like MPLS) allow us to quantitatively analyze the trade-off between energy cost and level of protection and robustness. Results show that with optimal strategies significant savings, up to 30%, can be achieved even when survivability is fully guaranteed.

Keywords: Energy-Aware, Traffic Engineering, Network resiliency, Shared protection, Dedicated protection.

TC-II

15:15 - 16:30
Room: Miguel Ângelo II

Wireless networks

chair: Alexandre Cunha

1 - Design of Optical Wireless Networks with Elastic Traffic Flows

Artur Tomaszewski, *Warsaw University of Technology, Warszawa, Poland*,
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The paper presents a method of optimising the wireless optical network that carries elastic packet traffic. The particular focus is on modelling the effect of elastic traffic flows slowing down in response to the decrease of the optical transmission systems' capacity at bad weather conditions. A mathematical programming model of the network design problem is presented that assumes that the packet rates of the elastic traffic flows decrease fairly. While practically any subset of network links can be simultaneously affected by unfavourable trans-

mission conditions, a particular challenge of solving the problem results from a huge number of network states considered in the model. Therefore, it is presented how the problem can be solved by generating the most unfavourable network states. Moreover, it is proved that it is entirely sufficient to consider only the states that correspond to the decrease of capacity on a single link. Finally, as the general problem is non-linear, it is shown that the problem can be transformed to a linear MIP problem and solved effectively when single-path routing of traffic flows is assumed.

Keywords: optical wireless networks, elastic traffic, multicommodity flow networks, resilient network design.

Acknowledgement: The work was supported by Poland's National Science Center under Grant No. 2011/01/B/02967.

2 - Exact approaches for power aware configuration of wireless sensor networks

Fabian Castaño, *Universidad de los Andes and Université de Bretagne-Sud*, fabian.castano@univ-ubs.fr

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This research deals with the problem of finding a minimum energy connected structure in wireless sensor networks that guarantees total target coverage. The problem is formulated as a Node Weigted Steiner Tree and an integer model to solve it is proposed. In order to solve the problem, a branch-and-cut algorithm based on Benders' decomposition is provided. Additionally, a more general algorithm is provided by considering an exponential set of constraints used to guarantee connectivity. An extensive set of experiments is used to demonstrate the effectiveness of the proposed approaches. The results are promising and indicate that the methods are efficient to solve moderated size instances in low computational times.

Keywords: Wireless sensor networks, Node Weighted Steiner Tree, Branch-and-cut, Benders Decomposition.

3 - Models and heuristic for Integrating Sink Location, Density Control and Routing Problems in Wireless Sensor Networks

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In this paper, we propose a new network design topology aiming at integrating the Sink Location, Density Control and Routing Problem (SLDCRP) in Wireless Sensor Networks. SLDCRP explicitly aims at maximizing the total energy available at the end of a given planning horizon, in the hope of extending network lifetime. Like in other approaches, SLDCRP divides the planning horizon into a finite discrete set of smaller periods of time. For each of these, optimal sink location, density control policies and data routes represented by trees are thought. Differently from other approaches in the literature where the sink is kept fixed in a multi-period approach like ours, the sink is allowed to move, at discrete moments in time, when one time interval changes to the next. We formulate SLDCRP as an integer programming problem and introduce a heuristic for it. Results indicate that the

heuristic is capable of finding good solutions, with smaller computing times, when compared to a Branch-and-cut method, also discussed here. By means of simulation, we compare our approach to another that does not use sink mobility. Simulation results indicate that better quality of service parameters are obtained when our model is used to plan the network.

Keywords: Wireless Sensor Network, Branch-and-cut, Heuristics, Simulation.

TD-I

16:45 - 18:00
Room: Miguel Ângelo I

Survivability networks II

chair: Walid Ben-Ameur

1 - Algorithms for Link Protection Problems in Networks

Bin Hu, *Vienna University of Technology*, hu@ads.tuwien.ac.at
Co-author(s): Günther Raidl (raidl@ads.tuwien.ac.at), Vienna University of Technology.

We consider a family of problems where the goal is to protect critical links in a network infrastructure against failures so that if a given number of unprotected edges fail, the network still fulfills certain quality aspects. As concrete examples we consider two problem variants where we either want to maintain a small network diameter or we want to avoid exceeding bandwidth limits on edges during package transfers. For the case where more than one edges may fail simultaneously, these problems are shown to be NP-hard. We propose polynomial algorithms to transform these problems into set covering problems which can be solved with a general purpose integer linear programming solver such as CPLEX. As a result we obtain provably optimal solutions with respect to minimizing the number of links that must be protected. While the overall concept can easily be adapted to other variants of link protection problems, we apply GPU-based parallel programming or incremental evaluation during dynamic programming in specific cases in order to speed up the transformation process. Results on random benchmark instances and instances derived from real-world networks show that this approach is able to handle problems of substantial sizes within viable time.

Keywords: Survivable network design, mixed integer programming.

2 - An optimization model for communication networks resilient to partial multiple link failures

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This submission is devoted to optimization of networks that permanently experience fluctuations of the capacity available on their links. This is an important and novel topic since

limited link availability is a fundamental feature in wireless networks and yet majority of work in survivable network design is restricted to the total single link failures. We assume a given finite set of network states. Each state is characterized by availability coefficients specifying, for each link, the fraction of its reference capacity available in this state, and by traffic coefficients specifying, for each demand, the proportion of its reference traffic to be realized in the considered state. Our routing strategy allows for thinning/thickening the reference path-flows, with the thickening limited by a given upper bound U of the reference value. Thus, in each state, the value of every path-flow can range from 0 to U times its reference value. For the corresponding link cost minimization problem (where link capacities and state-dependent path-flows are decision variables) we present a non-compact linear programming model together with a solution algorithm based on path generation. We illustrate the effectiveness of the introduced routing strategy by presenting numerical results for a set of representative network examples.

Keywords: survivable networks, partial multiple failures, path generation.

Acknowledgement: The work of French co-authors was carried out in the framework of the Labex MS2T, which was funded by the French Government, through the program "Investments for the future" managed by the National Agency for Research (Reference ANR-11-IDEX-0004-02). M. Pioro and M. Zotkiewicz were supported by National Science Center (Poland) under grant 2011/01/B/02967.

3 - Failure-disjoint paths

Walid Ben-Ameur, *Samovar, Telecom SudParis, France*, walid.benameur@telecom-sudparis.eu

Co-author(s): {Mateusz Żotkiewicz (mzotkiew@tele.pw.edu.pl), Michal Pióro (mpp@tele.pw.edu.pl)}, Warsaw University of Technology, Poland.

Given a set of commodities and a network where some arcs can fail while others are reliable, we first consider the problem of computing a minimum-cost pair of paths not sharing failing links. If a reliable link belongs to both paths then its cost is counted only once. We show that this problem can be solved in strongly polynomial time. Second, we consider a routing problem where each commodity can be split among pairs of failure-disjoint paths. We present a compact linear formulation of the problem. Also three non-compact formulations solvable by column generation are introduced. All formulations are numerically compared.

Keywords: Shortest paths, disjoint paths, compact formulations, column generation, capacitated network design.

TD-II

16:45 - 18:00
Room: Miguel Ângelo II

Energy aware network design

chair: Arie Koster

1 - A Branch and Benders Cut Approach for Nonlinear Location-Design in Green Wireless Local Area Networks

Bernard Gendron, *CIRRELT and DIRO, Université de Montréal*,
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We consider problem arising in the design of Green (or energy-saving) Wireless Local Area networks (GWLANs). In this context, decisions on the location of access points, on the assignment of user terminals to the opened access points, as well as on the assignment of one power level to each opened access point, have to be taken simultaneously. In particular, the power level assigned to an access point a ffects, in a nonlinear way, the capacity of the connections between the access point and the user terminals that have been assigned to it. We model the problem as an integer program with nonlinear constraints, to handle such an intrinsec nonlinearity of the connection capacities. We derive several kinds of valid inequalities, and solve the proposed nonlinear formulation by a Branch and Benders Cut approach.The approach has been tested on a large set of GWLAN instances, and compared to a more traditional Benders decomposition approach on a subset of the GWLAN testbed. The computational results show the superiority of the proposed Branch and Benders Cut approach in terms of both scalability and robustness. Furthermore, solutionsof better quality are returned.

Keywords: Green wireless local area network, Facility location, Network design, Benders decomposition, Branch and cut.

2 - Network Design with Compression I: A Polyhedral Study

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In the context of (telecommunication) networks, the topics of network design and routing are persistent in optimization history for the past decades. Besides the inherent difficulty of network design problems, recent developments in network technology pose new and challenging problem variations. One particular difficult version is the network power consumption problem (NPC), where the network dimensioning component is enriched by the possibility to add compressors to nodes, decreasing size of data streams but increasing energy consumption. A mixed integer linear program (MILP) formulation of NPC was presented in previous work, see Extended Cutset Inequalities for the Network Power Consumption Problem by Koster,

Phan and Tieves, ENDM 2013. However, an exact solution (for reasonable sized instances) is practically not obtainable by straightforward implementations with nowadays MIP solvers. Providing a theoretical foundation for custom branch & cut algorithms, we present results on the underlying feasibility space. We derive facet defining inequalities and present results for aggregating facets from smaller sized networks. Especially, we show how the famous cut-set inequalities can be lifted (and extended) for the NPC problem. Concluding we show how our results can be extended to the Γ-robust case, presenting Γ-robust versions of the (extended) cut-set inequalities.

Keywords: Telecommunication, Combinatorial Optimization, Facets, Polyhedron.

3 - Network Design with Compression II: A Complexity Study

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A recent challenge in (telecommunication) networks is the network power consumption problem (NPC). There, the classical network-design problem is enriched by the possibility to attach compressors to nodes, decreasing size of data streams but increasing energy consumption. Although the problem can be formalized as mixed integer linear program, an exact solution for practical applications remains out of reach for stand-of-the-art solvers, see Extended Cutset Inequalities for the Network Power Consumption Problem by Koster, Phan and Tieves, ENDM 2013. We present a detailed analysis of the problem's theoretical difficulty. Since NPC is an extension of classical network design problems, it is obviously NP-hard in general. Therefore, we concentrate on special cases, like the subproblem of compressor palcement, fixing the routing already. This stresses that NPC's difficulty is not only induced it's origin in network design, but that the possibility of adding compression bears its own difficulty. Our work concludes by a polynomial time algorithm for special cases on path graphs.

Keywords: Telecommunication, Complexity, Combinatorial optimization.

Doctoral Dissertation Competition

1 - A Polyhedral Approach for Solving the Two-Facility Network Design Problem

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Advisor: Yogesh K. Agarwal

The thesis studies the problem of designing telecommunication networks using transmission facilities of two different capacities. The point-to-point communication demands are met by installing a mix of facilities of both capacities on the edges to minimize total cost. We consider 3-partitions of the original graph which results in smaller 3-node subproblems. The extreme points of this subproblem polyhedron are characterized using a set of propositions. A new approach for computing the facets of the 3-node subproblem is introduced based on polarity theory. The facets of the subproblem are then translated back to those of the original problem using a generalized version of a previously known theorem. The approach has been tested on several randomly generated and real life networks. The computational results show that the new family of facets significantly strengthen the linear programming formulation and reduce the integrality gap. Also, there is a substantial reduction in the size of the branch-and-bound (B&B) tree if these facets are used. Problems as large as 25 nodes and 50 edges have been solved to optimality within a few minutes of computer time.

Keywords: Integer programming, polyhedral theory, polarity, facet-inequalities, telecommunications.

2 - Robustness Concepts for Knapsack and Network Design Problems under Data Uncertainty

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Advisor: Arie Koster

In this thesis, we consider mathematical optimization under data uncertainty using mixed integer linear programming (MILP) techniques. Our investigations follow the deterministic paradigm known as robust optimization. It allows to tackle an uncertain variant of a problem without increasing its complexity in theory or decreasing its computational tractability in practice. We consider four robustness concepts for robust optimization and describe their parametrization, application, and evaluation. The concepts are Γ-robustness, its generalization multi-band robustness, the more general submodular robustness, and the two-stage approach called recoverable robustness. For each concept, we investigate the corresponding robust generalization of the knapsack problem (KP), a fundamental combinatorial problem and subproblem of almost every integer linear programming (ILP) problem, and many other optimization problems. We present ILP formulations, detailed polyhedral investigations including new classes of valid inequalities, and algorithms for each robust KP. In particular, our results for the submodular and recoverable robust KP are novel. Additionally, the recoverable robust KP is experimentally evaluated in detail. Further, we consider the Γ-robust generalization of the capacitated network design problem (NDP). For example, the NDP arises from many application areas such as telecommunications, transportation, or logistics. For the Γ-robust NDP, we present MILP formulations, detailed polyhedral insights with new classes of valid inequalities, and algorithms. Moreover, we consider the multi-band robust NDP, its MILP formulations, and generalized polyhedral results of the Γ-robust NDP. Furthermore, we present computational results for the Γ-robust NDP using real-life measured uncertain data from telecommunication networks. These detailed representative studies are based on our work with the German ROBUKOM project

in cooperation with Nokia Siemens Networks GmbH & Co. KG. Finally, we give concluding remarks on the presented robustness concepts and discuss future research directions.

Keywords: Γ-Robustness, Multi-Band Robustness, Submodular Robustness, Recoverable Robustness, Robust Knapsack Problem, Robust Network Design Problem.

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