Optimization of passive optical network planning for fiber-to-the-home applications

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Declaration

I, Samuel van Loggerenberg hereby declare that the dissertation entitled "Optimization of passive optical network planning for fiber-to-the-home applications" is my own original work and has not already been submitted to any other university or institution for examination.

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Abstract

Passive optical networks (PONs) are point-to-multipoint networks where a single Central Office (CO) is connected to a number of downstream Optical Network Units (ONUs) via a single optical fiber by splitting the optical signal with passive splitters. Due to technology advances and increasing bandwidth requirements, these networks have moved to last mile deployment, also known as fiber-to-the-home (FTTH).

The planning of these PONs are traditionally done by hand, but automated methods can be used to decrease deployment costs and planning time. Even though a number of methods have been proposed to address this problem through the solving of integer linear programming (ILP) models, they suffer from limited availability, inaccuracies and limited scalability due to the problem complexity.

This dissertation focusses on improving the accuracy of these models as well as improving scalability to a point where large-scale problems can be solved feasibly. To address this, a basic model is implemented to capture the network structure and verified accordingly. Results show this model can be solved quickly, but has large discrepancies with real-world plans.

Refinements in the form of fiber duct sharing, network constraints, multiple splitter types and economies of scale among others are then incorporated into a refined model and solved. Analysis of the experimental results indicates improved accuracy and lower deployment costs, at the expense of increasing computation effort considerably.

Heuristic techniques are then examined to improve computational performance, including an elementary heuristic (ELEM), the Branch Contracting Algorithm (BCA) and problem decomposition. It is demonstrated that through the use of *k*-means clustering, the refined model can be solved in a fraction of the time while keeping deployment costs comparably low.

Keywords: *Clustering, FTTH, Heuristics, MILP, Optimization, Passive Optical Networks, Planning*

Opsomming

Passiewe optiese netwerke is punt-tot-multipunt netwerke waar ′n enkele sentrale kantoor aan ′n aantal stroomaf optiese netwerk eenhede verbind is deur ′n enkele optiese vesel. Die optiese sein word deur middel van passiewe optiese verdelers versprei. As gevolg van tegnologie verbeterings en toenemende bandwydte vereistes, het hierdie netwerke beweeg na laaste myl ontplooiing, ook bekend as vesel-tot-die-huis (FTTH).

Die beplanning van hierdie netwerke word tradisioneel met die hand gedoen, maar outomatiese metodes kan gebruik word om implementeringskoste en beplanningstyd te verminder. ′n Aantal metodes is reeds voorgestel om hierdie probleem aan te spreek, meestal deur die oplos van heeltallige lineêre programmeringsmodelle. Weens die kompleksiteit van die probleem, ly hierdie metodes egter aan beperkte beskikbaarheid, onakkuraathede en die beperkte vermoë om grootskaalse probleme doeltreffend op te los.

Hierdie verhandeling fokus op die verbetering van die akkuraatheid van hierdie modelle sowel as die bevordering van werksverrigting tot ′n punt waar grootskaalse probleme in ′n billike tyd opgelos kan word. Om hierdie aan te spreek, is ′n basiese model geïmplementeer om die netwerk struktuur vas te vang. Hierdie model word dan ook geverifieer. Resultate bewys dat die model vinnig opgelos kan word, maar die oplossing vertoon groot afwykings vanaf werklike planne.

Verfynings in die vorm van onder andere optiese vesel kanaaldeling, netwerk beperkings, verskillende tipes verdelers en skaalvoordele word saamgevat in ′n verfynde model wat dan opgelos word. Ontleding van die eksperimentele resultate dui op verbeterde akkuraatheid en laer ontplooiingsonkostes, alhoewel werksverrigting prysgegee word.

Heuristiese tegnieke word dan ondersoek om werksverrigting te verbeter, insluitend ′n elementêre heuristiek (ELEM), die *Branch Contracting* Algoritme (BCA) en probleem ontbinding. Verder word getoon dat deur die gebruik van die *k-means* trosvormingsalgoritme, die verfynde model opgelos kan word in ’n breukdeel van die tyd terwyl ontplooiingsonkostes laag bly.

Sleutelterme: *Beplanning, FTTH, Heuristiek, MILP, Optimering, Passiewe Optiese Netwerke, Trosvorming*

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List of Acronyms

AE Active Ethernet

APON ATM PON

ATM Asynchronous Transfer Mode

BCA Branch Contracting Algorithm

CAPEX Capital Expenditure

CD Cable Distribution

CIL Channel Insertion Loss

CO Central Office

COs Central Offices

DARPA Defense Advanced Research Projects Agency

DSL Digital Subscriber Line

EFM Ethernet in the First Mile

EOS Economies of Scale

EPON Ethernet Passive Optical Network

FSAN Full Service Access Network

FTAM File Transfer and Access Management Protocol

FTP File Transfer Protocol

FTTB Fiber to the Building

FTTC Fiber to the Curb

FTTH Fiber to the Home

FTTN Fiber to the Node

FTTx Fiber-to-the-x

GA Genetic Algorithm

GIS Geographic Information System

GPON Gigabit Passive Optical Network

HTTP Hypertext Transfer Protocol

IEEE Institute of Electrical and Electronics Engineers

IETF Internet Engineering Task Force

ILP Integer Linear Program

IP Internet Protocol

IPGs Interpacket Gaps

IPTV IP Television

ISO International Organisation for Standardisation

ITU-T International Telecommunication Union - Telecommunication Standardisation Sector

LLID Logical Link ID

LP Linear Program

MILP Mixed Integer Linear Programming

MLAP Multifacility Location-Allocation Problem

MST Minimum Spanning Tree

OLT Optical Line Terminal

ONU Optical Network Unit

ONUs Optical Network Units

OSI Open Systems Interconnection

P2MP Point-to-Multipoint

P2P Point-to-Point

PDUs Protocol Data Units

PMD Physical Medium Dependent

POI Point of Interest

PON Passive Optical Network

PONs Passive Optical Networks

RARA Random Allocation and Reallocation Algorithm

ROI Return on Investment

SA Simulated Annealing

SMTP Simple Mail Transfer Protocol

SPs Service Providers

SSD Solid-State Drive

TC Transmission Convergence

TCP Transmission Control Protocol

TDM Time Division Multiplexing

VDSL Very-high-bit-rate Digital Subscriber Line

VOIP Voice-over-IP