

Chapter 1

Introduction

In this chapter, an introduction is given to the research. Background information, motivation for the research, research goals and objectives along with the complete methodology is detailed before concluding with an overview of the rest of the dissertation.

1.1 Background

Fiber-based networks are typically categorised as either Point-to-Point (P2P) or Point-to-Multipoint (P2MP). With P2P solutions, the subscriber links directly to the Central Office (CO) or exchange with a dedicated fiber, while P2MP solutions share a single fiber across multiple subscribers. Even though dedicated fibers provide the best future proofing in terms of bandwidth, it comes at a prohibitive cost when large numbers of subscribers are involved. Depending on the length of the fiber loop, a dedicated infrastructure can be up to 100 percent more expensive [1] than a shared solution and therefore most Service Providers (SPs) opt for a shared infrastructure.

With this tendency to implement fiber networks, fiber has moved from backbone to

last mile deployment through Fiber to the Node (FTTN), Fiber to the Curb (FTTC), Fiber to the Building (FTTB) and finally Fiber to the Home (FTTH) [2]. This is mostly due to technology and standard advances which result in reduced fiber deployment cost and easier integration with the rest of the network. Of these deployments, the most notable are the Gigabit Passive Optical Network (GPON) [3–6] standard which is based on ATM PON (APON) and Ethernet Passive Optical Network (EPON) [7] which is a derivation of the existing IEEE 802.3 standard.

Both GPON and EPON have a similar physical layer structure, consisting of an Optical Line Terminal (OLT) at an exchange or CO, serving a number of passive optical splitters, which in turn distribute the signals to a number of Optical Network Units (ONUs). Each Optical Network Unit (ONU) then has a specified number of service ports depending on the customer requirements. This results in a tree structure, with a single fiber from the CO serving several dozens (up to 128 in the case of GPON [1]) of ONUs.

As with any other network deployment, planning plays a fundamental role in both the overall cost of deployment and the resulting network efficiency. Planning of fiber networks is traditionally done manually by planners trying to find a sufficiently optimal solution for a given number of nodes. Even though these plans are close to optimal for smaller networks, large network plans are usually sub-optimal, time consuming and require experienced planners. With the use of planning optimization, this process can be automated to produce optimal solutions for basic models in minutes.

1.2 Motivation

With the growing popularity of bandwidth intensive services such as online video streaming, high definition IP Television (IPTV) and video conferencing, SPs are increasingly investing in broadband access. According to [8], international bandwidth demand increased 45 % in 2011, with aggregate capacity requirements doubling every two years. Even though competing broadband solutions such as Digital Subscriber Line (DSL) and WiMAX exist, they are limited in range due to noise susceptibility and

do not provide the necessary bandwidth required by these services. Therefore, SPs are now turning to fiber-based networks and in particular Passive Optical Network (PON) to meet the current and future needs of subscribers.

In South Africa, a number of local and foreign companies are now investing in FTTH applications, with i3 Group Ltd investing R5 billion to provide the Durban area with fiber infrastructure [9]. Worldwide, FTTH is gaining tremendous attention, with Japan and Europe implementing large scale projects in major cities [10]. Although a number of successful projects are already deployed, widespread adoption is still not realized fully and thus the need for both brown- and greenfield planning techniques are great, especially due to the limited number of works in this field.

1.2.1 Accuracy vs feasibility issue

By using automated methods, planning time can be greatly reduced, with basic problems solved in mere minutes, producing a near-optimal deployment plan for minimum cost, widest reach or least fiber. This allows FTTH adoption to accelerate due to lower costs and will provide for the future needs of subscribers. There does however exist challenges with these basic problems:

- **Availability:** The availability of models of the PON planning problem is limited, with only a handful of authors addressing the specific problem.
- **Model accuracy:** The models that are available only include the most basic elements of the planning problem and do not take into consideration general network and economic constraints such as economies of scale, network reach or differences in fiber costs [11]. The largest deviation of these basic models is usually the exclusion of fiber duct sharing, with each fiber modelled to have a dedicated duct, something not encountered in any practical implementation.
- **Feasibility:** Producing more accurate models of the planning problem increases the amount of constraints and therefore the computational complexity, usually to

a point where the model can not be solved in a feasible amount of time [2,12].

- **Scalability:** Even though some methods can be used feasibly to solve small problems with relative ease, they are incapable of solving larger problems since their computational complexity scales exponentially.

Therefore, a compromise is needed where accuracy and computational performance are weighed against each other. It is this difficulty that is addressed in the research contained in this dissertation.

1.3 Research goal

The overall research goal is to answer the following: "How can large scale PON planning for FTTH applications be done accurately through automatic methods?". This dissertation aims to provide answers to this question by breaking it up into the following three research questions:

- How can a basic model of the PON planning problem be improved in terms of accuracy?
- What is the quantitative improvement of this refined model?
- Can this refined model be feasibly used to solve a large-scale PON?

1.4 Research objectives

The proposed research has the following objectives:

- Generate theoretical data for a PON deployment.

- Reimplement a basic mathematical model for a PON based on the model by Poon et al. in [11].
- Solve the model through the use of CPLEX [13] and test solution feasibility.
- Alter the model to accept more practical real-world test data.
- Increase the accuracy of the model by incorporating factors such as coverage, splitter types and duct sharing.
- Optimize the solution algorithm through the use of heuristics, meta-heuristics and/or valid inequalities for faster execution.
- Compare both feasibility and speed against other known techniques.

1.5 Research methodology

The basic outline of the proposed research methodology is shown in figure 1.1. First, a literature review is done to extract a number of critical precursors to the research, including possible objectives (section 1.4), the research motivation (section 1.2) and the necessary background information (section 1.1).

As all the information is extracted from the literature, a research problem is found through analysing the advantages, disadvantages and possible shortcomings of the precursors. This is done to arrive at the research problem (section 1.3).

Then, when moving on to the literature study, the specific field's literature is analysed to determine how the problem of planning is currently solved, how these techniques are applied and what the specific issues involved are (chapters 2 and 3). Through this analysis, possible future challenges in the specific implementation of automatic methods can become evident, necessitating early intervention in the design process.

Upon completion of the literature study, the feasibility of a solution to network planning can be assessed. This includes the predicted response of the model in question

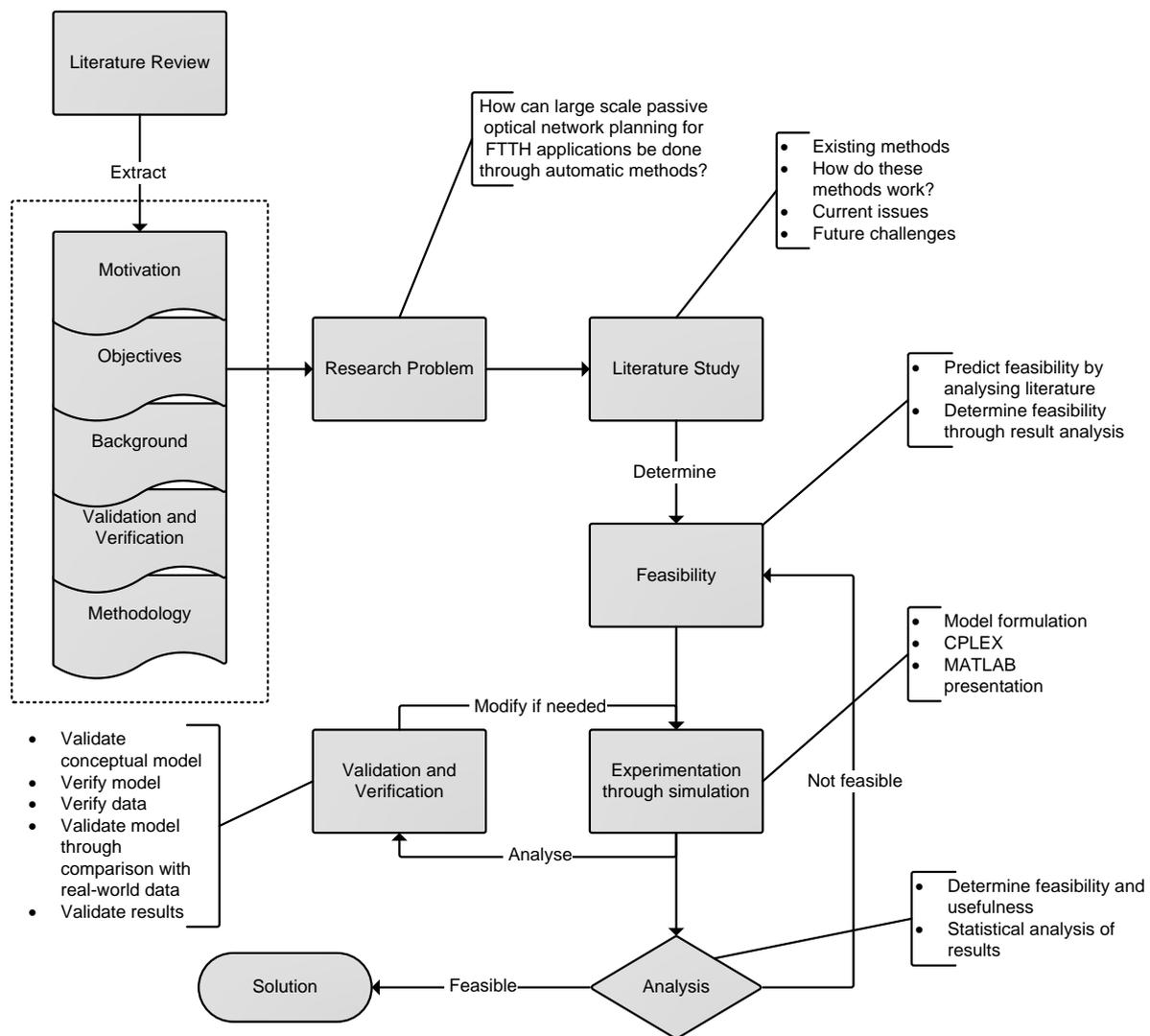


Figure 1.1: Research methodology

and if those results will be feasible and useful. The feasibility step is also repeated after experimentation to ensure the feasibility of the final solution.

Once feasibility of the mathematical model and proposed solver is confirmed, the research reaches an iterative process of experimentation, simulation, validation and verification. The model is formulated mathematically, solved with IBM ILOG CPLEX [13] and illustrated through the use of MATLAB [14] (chapter 4). This results in a graphical and numerical representation of the model solution.

Then, the validation and verification step ensues, verifying the conceptual model, mathematical model and data through feasibility and logical analysis (section 4.4.2).

Once the solution and model is verified, the result is validated against previous studies' findings and with real-world data (chapter 6). If at any point the validation or verification process fails, the model is revised and the experimentation and simulation step restarts.

This process is then repeated iteratively until a validated solution is found. Complexity will also tend to increase iteratively as simple mathematical models make way for more complex and complete models to match the expected results.

1.5.1 Validation and verification

In the field of mathematical modelling, verification and validation is notoriously difficult, with a number of papers trying to address this problem [15–17]. As stated by these authors, no simulation model can be completely verified or validated, as the nature of modelling is the approximation of the behaviour of a system.

According to [16], no specific algorithm or procedure can apply to all models, requiring methods specific to the model in question. In [17], Carson suggests a framework for validation and verification of a general simulation model as follows:

1. **Face validity** - Is the logic in the conceptual model correct and are the input-output relationships reasonable?
2. **Parameter range** - Test the model over a range of input parameters.
3. **Comparison** - Where applicable, compare model predictions to past performance of the system or to a baseline model representing an existing system. When designing a new system, compare implemented model behaviour to assumptions and specifications.

This procedure will be followed when validating the model in each iteration so that all versions will display face validity. Furthermore, tests will be done on as many sources

of input data as available and applicable, reducing potential bias introduced in results due to data parameters. As stated in the third point of the framework, implemented model behaviour will be continuously compared to all assumptions concerning the overall PON planning problem (chapters 4 and 5).

Finally, since the model is implemented in C++, verification will also be done according to software engineering principles, ensuring correct translation from mathematical model to program code.

1.6 Dissertation overview

The rest of the dissertation is as follows: Chapter 2 introduces all technical aspects of PONs relevant to the planning problem while chapter 3 details the concepts pertaining to modelling and the methods used to solve them.

Chapter 4 details the development of a basic model describing the PON planning topology, which is verified using a comparison with a hand-calculated solution. This model is then refined in chapter 5 to improve its accuracy through the addition of fiber duct sharing and other constraints.

In chapter 6, the refined model of chapter 5 is solved using heuristic techniques to improve its computational performance, allowing feasible usage for large-scale problems. These solution techniques are also validated against a known heuristic in the same chapter.

Finally, chapter 7 contains concluding remarks on the basic, refined and heuristically solved models and includes recommendations for future research.