

Chapter 7

Conclusions and recommendations

This chapter concludes the dissertation with a summary of the research done and its function in answering the research questions. Finally, recommendations for future research are provided before closing with some noteworthy results.

7.1 Concluding summary

In chapter 1, the following three research questions were introduced:

- 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?

These questions form the basis of the research done and the contribution made in this dissertation. Following this, a comprehensive literature study was given, describing

the technical aspects of the problem in chapter 2 and the modelling and optimization aspects in chapter 3.

In chapter 4, the premise for the first research question was realized by implementing a basic model of the PON planning problem. After verifying the model through the use of randomly generated datasets, it was concluded that the basic model captures the network topology of the problem, but fails to deliver an accurate estimation of the deployment cost.

The first research question was answered through the refinements done in chapter 5. Extensive testing was done on each improvement, noting decreases in deployment cost and increases in computational complexity. Ultimately, the complete model was tested to answer the second research question, revealing an average improvement in deployment cost of 47.8 % across all datasets.

Unfortunately, the additional constraints introduced in the refined model pushed the required computational effort into infeasibility, especially for large datasets such as *HugeNet*. By using heuristic techniques described in chapter 6, the computational performance of the refined model was increased to a point where large-scale plans could be feasibly solved, showing a reduction of more than 90 % in the time to solve and by extension answering the third research question.

Finally therefore, we can conclude by saying that it is indeed possible to improve a basic model of the PON planning problem to a large extent and also to use this refined model to solve large-scale problems such as *HugeNet* in a feasible amount of time.

7.2 Future work

Recommendations for future work can be divided into two distinct groups: improving the accuracy of the model or improving the computational performance of the solution.

7.2.1 Model improvement

As expected, the refined model produced in chapter 5 can be further expanded to include additional aspects of the PON planning problem. These include:

- Modelling of individual ports
- Modelling of micro ducts
- Termination and interconnects
- Redundancy and future proofing
- Alternative paths for fiber duct sharing
- Stochastic demand

To take the topology of the PON planning problem to the extreme, a model can be constructed to include everything up to the individual ports on every splitter and every ONU. This allows for even greater accuracy in terms of both details in the resulting network plan and costs associated. A model containing port usage also ensures that only the optimal configuration and interconnecting of splitters, ONUs and COs is contained in the model solution, removing all doubts concerning practical deployment.

In terms of fiber connectivity, a model can also be constructed to include modelling of each micro duct, ensuring the installation of correct duct sizes and the possibility of using lower cost ducts or pre-existing ducts. Furthermore, fiber termination and interconnects can be modelled to increase accuracy even further, allowing the model to provide a solution that specifies duct part numbers and splicing specifications.

A large component in practical network deployments is that of redundancy and future proofing. Additional fibers in key areas allow for higher service availability and reliability, giving SPs the option of providing higher cost, high availability solutions

to customers in specified locations. In terms of future proofing, ducts can be optimally sized according to future predicted demand, avoiding more expensive network upgrades at a later stage.

In chapter 5, a heuristic was used in terms of the number of shortest paths to include in the model. By increasing the number of possible paths, the total length of ducts shared can be increased, decreasing overall deployment cost. A study as to a reasonable number to include can be done to balance computational complexity with decreased deployment cost.

Finally, a model containing stochastic demand would provide a better representation of typical greenfield network plans, as they are deployed with only partial knowledge of current and future demand. This would undoubtedly increase the complexity of the model significantly, possibly requiring an approach to identify *good* candidates before solving.

7.2.2 Solution improvement

To improve the computational performance of the refined model, it is recommended to determine the viability of using a more sophisticated clustering technique than k -means, incorporating knowledge of possible interconnectivity in the clustering stage. Possible candidates include variations of the OPTICS method [63] or EM clustering [64].

Furthermore, the calculation of *valid clusters* can be improved, since integration with the previous cluster could lead to awkwardly spaced clusters. It is recommended to determine the best candidate cluster to combine invalid clusters with, possibly through average or maximum distance minimization.

Concerning solution improvement in general, it is recommended to determine viability of meta-heuristics as well as row or column generation to improve computational performance, as this was not addressed in the research done in this dissertation.

Finally, a study to determine a lower bound for the PON planning problem as approximated by the refined model could lead to a more accurate figure in terms of deployment cost performance or true deviation from optimal where the clustering method is concerned.

7.3 Closure

In conclusion, from the research conducted, it is proven that automated methods exist to solve large-scale PON plans in a feasible amount of time. Due to the amount of alternatives and the high monetary stakes involved however, studies will need to be conducted to compare different methods and determine the best solution to this particular problem.

Unsurprisingly, it is also evident that when trying to solve this problem, a definite *compromise* is needed between computational performance and overall deployment cost, with the priority and emphasis of each determined by the user of the resulting solution.