A New Modelling Approach Is Required to Help Mobile Network Operators Handle the Growing Demand for Data Traffic

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Abstract: Last year, global mobile data traffic grew by 69%, and similar growth rates are expected in the coming years. This growth affects the quality of service, and mobile network operators are finding it increasingly difficult to manage mobile data traffic. To this end, they are drastically increasing the number of sites and antennae, as well as modernising existing networks. This requires selecting the best antenna locations in terms of service area coverage, spectrum availability, installation costs, demographics, etc. In addition, when extending the wireless network with new antennae, the radio-electrical parameter settings of new and neighbouring antennae require (re)calibration to minimise interference—a process that in principle may affect the entire network. Moreover, the antennae must connect to the core network and influence it. This complex optimisation planning problem does not lend itself well to a manual solution approach. Still, these plans are developed "manually", with the support of IT tools, through a time-consuming and inefficient trial-and-error process. Applied optimisation is needed to tackle this problem effectively, but this requires advancing the state-of-the-art: Most papers focus on solving the different sub-problems independently. However, these affect each other heavily and they must be considered simultaneously to maximise the offered service: optimising the location and configuration of new antennae and the configuration of wireless network radio-electrical parameters, while taking into account access to the core network.

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1 INTRODUCTION

Last year, global mobile data traffic grew by 69% (CISCO, 2015), and similar growth rates are expected in the coming years[1]. This growth affects the quality of service, and mobile network operators (MNOs) are finding it increasingly difficult to manage mobile data traffic during peak times (Rivanda, 2015). The telecom community expects that MNOs will need about 1,000 times today's capacity to handle the demand in 2020 (NGMN, 2015). Consequently, MNOs are trying to access additional bandwidth, which is a scarce and congested resource. Moreover, MNOs are drastically increasing the number of sites with antennae, as well as modernising part of the existing network.

These are challenging planning tasks. To satisfy evermore-common increases in demand, planners are required to select appropriate locations for installing new base stations and to configure radio-electrical parameters[2] both of the new and pre-existing antennae. This involves finding efficient locations among a large number of candidate sites, while considering service area coverage, spectrum availability, installation costs, demographics, etc. In

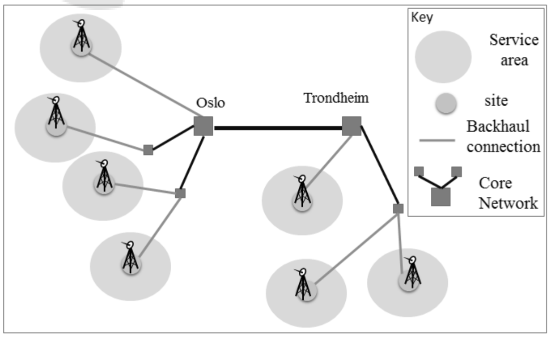

Figure 1: Wireless and backhaul network.

[1]Mobile data traffic is expected to grow at a compound annual growth rate of 57% from 2014 to 2019 (CISCO, 2015).

[2]E.g. power emission, transmission frequency, tilt, height, antenna diagram or type and many more.

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addition, when extending the wireless network[3] with new antennae, the antennae may interfere with each other, and the parameter settings of neighbouring antennae might need recalibration to increase coverage while trying to minimise interference.

Furthermore, the wireless network must connect to the *core network*, via *backhaul* connections (wireless, copper or through fibre optic cables) (see Figure 1). The set of connections in the backhaul must be adjusted whenever changes in the wireless network take place or when traffic volumes increase. Clearly, all above planning decisions affect each other and they should be taken jointly to maximise the offered service. Access to the backhaul network in particular is expected to become a major bottleneck in the coming years (NGMN, 2012). With the drastic increase in the number of sites/antennae, the problem of choosing the best sites, calibrating the radio-electrical parameters and establishing low-cost backhaul connections might need to be solved several times per month for a given area. This is a complex combinatorial optimisation problem where, for even a small version with few antennae, the amount of possible combinations of parameters and decisions quickly exceeds what a human can evaluate manually. Infrastructural investments, whether installing antennae or new connections to the backhaul network, are generally very costly, so planners are put under great pressure by MNOs to minimise overall capital and operational expenditures. Today, this planning task is carried out by specialised personnel (*mobile network planners*) in a time-consuming and inefficient trial-and-error process. Most existing planning tools only present functionalities to assist in the manual planning process. To our knowledge, the few tools that do use optimisation techniques for automated planning only handle simplified versions of the problem (e.g. fewer parameters).

The paper is organised as follows: Section 2 provides a brief literature background on the optimisation of mobile network planning. Section 3 describes the current approach used by MNOs and its limitations, our arguments for using optimization in the planning process and the research challenges that have to be overcome to do so. Section 4 concludes the position paper.

[3]Normally, this part of the mobile network is called the *wireless access network*. For the sake of simplicity, we drop the term "access" in this paper.

2 BACKGROUND

The literature on optimisation applied to the design of wireless and mobile networks is very wide. It dates back to the late 60s/early 70s, when the first works on frequency assignment appeared. The merit for introducing mathematical optimisation and graph colouring techniques for this type of problem is usually credited to (Metzger, 1970). Since these early works, devoted to frequency assignment, the focus has widened to encompass all the geographical, physical and radio-electrical parameters of wireless networks. These may include, e.g. antenna location, tilt, height, transmission frequencies, power emission, polarisation, diagram, etc.

Traditionally, the design of a mobile network has been decomposed into two major sub-problems:

- **Wireless Network Design (WND).** This can be summarised as the problem of 1) selecting appropriate locations for new base stations of a wireless network and 2) establishing radio-electrical parameters of the old and new antennae and assigning radio channels so the demand of service is satisfied and the overall installation and operational costs are minimised (e.g., Capone et al. 2006).
- **Backhaul Network Design (BND).** This consists of choosing the cheapest way to link the antennae to aggregation nodes (assumed already available), which provides the interface to the core network. Connections must meet quality of service and survivability requirements (Charnsripinyo and Tipper, 2005). Choosing the most adequate links will allow MNOs to sustain traffic and avoid the risk of seeing the backhaul become the bottleneck of the network (NGMN, 2012).

This conceptual subdivision is reflected both in the practice and in the literature of mobile network planning. The literature abounds with models and solution techniques for WND and BND (treated independently), which are both very difficult combinatorial optimisation problems. Since the early 1980s, several optimisation models have been developed to tackle WND (see Capone et al., 2006), at the time considered the bottleneck problem. The benefits of bringing these developments into practice were already pointed out in (Ceria et al., 1999). In 2005, Dehghan stated that the use of automatic- and optimisation-oriented planning techniques might lead to a cost reduction of up to 30%. Even if very limited, experiences show that the exploitation of optimisation techniques may produce significant increases in coverage (see e.g. Atesio, 2000 and Mannino et al., 2006). Typically, WND is further decomposed into two sub-problems (Capone et al., 2006): *coverage planning*, devoted to the choice of antenna localisation and radio-electrical parameters, and *capacity planning*, often denoted by *frequency assignment* (for a survey, see Aardal et al., 2007), where one wants to find an optimal assignment of radio channels to minimise overall interference. A successful attempt to combine the two sub-problems into a unique optimisation task was carried out in Mannino et al. (2006) for broadcasting networks and in D'Andreagiovanni and Mannino (2009) for WIMAX (Worldwide Interoperability for Microwave Access) mobile networks. From the existing literature, the successful approaches to WND often combine heuristic frameworks with mathematical optimisation, with emission powers represented by a continuous variable (as in Amaldi et al, 2006) or, more recently, by binary variables (as in D'Andreagiovanni et al., 2013). BND is typically modelled with mathematical programmes (e.g. Charnsripinyo and Tipper, 2005; Cox and Sanchez, 2000; Islam et al., 2015; Wu and Pierre, 2003). These models are then solved either heuristically or by using exact methods for small instances, as in Grøndalen et al. (2015). Few authors have attempted to solve WND and BND as a joint optimisation problem (e.g. St-Hilaire and Liu, 2011). In general, such attempts are limited to so-called metaheuristic approaches, without guarantee on the quality of the solutions produced.

3 TIME TO MODEL THINGS DIFFERENTLY

Current Approach and its Limitations. Today, mobile network planners perform their planning tasks 'manually', usually assisted by the available commercial tools; however, these only provide very basic support. From our experience, our literature research, and discussion with Teleplan Globe AS[4] and Telenor[5] the planners' current workflow can be summarised as follows: they iteratively identify possible locations for antennae, simulate their instalment and adjust the parameters of the new and pre-existing antennae accordingly. While choosing locations, they also check for possible backhaul connections. This time-consuming task is repeated until an acceptable result is reached. As mentioned, finding the best combination of location and parameter values for all of the network antennae is actually a very hard optimisation problem. Furthermore, the locations chosen should allow a (possibly least-cost) backhaul connection. The sheer number of possible decisions to explore makes a 'manual' approach clearly inefficient. Moreover, such tasks will in any case soon become impossible for the current workforce to carry out, given that the rapid increase in smaller cells (antenna coverage) constantly requires the installation of new antennae and the re-configuration of network parameters.

Need for Applied Optimisation. Some planning software providers claim that they embed optimisation in their tools. To our knowledge however, the tools used by practitioners have limited or no actual optimisation functionality. In addition, such tools never address the planning of the backhaul and wireless network jointly. Optimisation-based planning tools could substantially reduce the planning time and provide solutions that are more efficient, allowing MNOs to keep up with market demand and to enforce their customer policy at minimal costs, despite the sharp increase in demand. Such tools would also be beneficial for the public in general: their use would result in better coverage, increased capacity, reduced interference and reduced outages of the selected sites. Moreover, improved service could be crucial for critical/emergency services that require a stable connection. Optimising the layout of network elements and minimising interference will also lead to cleaner signals, where the energy usage is minimal for a given quality of service. Additionally, the predictability of the network will lead to reduced operational costs for the MNOs. The savings could be reinvested into installing new antennae and, in general, into improving and modernising the network's infrastructure. This positive externality will in turn contribute to improve further the quality of service and to connect a higher number of users. However, the limitations in existing systems are rooted in the status quo of related research. Indeed, the state-of-the-art in optimisation applied to telecommunications must be advanced to overcome these limitations and to achieve the above improvements.

Applied Research Challenges. In the optimisation literature (section 2), most approaches have either tackled somewhat stylised problems or focused on

[4]Provider of planning software for MNOs (http://teleplanglobe.no/)
[5]Norway's main mobile network operator (http://www.telenor.com/about-us/global-presence/norway/)

specific sub-problems. To have a substantial impact on the current practice requires designing richer models and algorithms that are more effective for the overall problem faced by mobile network planners. To interact with the planning process and to be used in practice, such algorithms should be capable to provide good or optimal solutions to the overall problem very quickly. More specifically, the following parts need to be planned jointly:

- The location and configuration of new antennae (WND).
- The configuration of wireless network radio-electrical parameters.
- The connection to the core network (BND).

Addressing these effectively requires facing critical modelling and algorithmic challenges. A unifying mathematical model to combine WND and BND must be devised, along with effective algorithmic schemes to solve the models in a reasonable amount of time for *real-life scenarios*. This is a clear challenge, as, to our knowledge, none of the methods presented in the literature has ever actually been applied in a real-life planning process. In summary, the following advancement in the state-of-the-art for WND/BND will be needed:

- Novel unified models for the joint optimisation of WND and BND.
- A fast and effective algorithmic framework for solving the unified model in a reasonable amount of time and producing good or optimal solutions for real-life instances.
- Modelling to tackling potential planning scenarios, including different wireless and backhaul techniques, topologies and a large numbers of parameters.

Our community must focus on designing such effective integrated approach. *First*, this requires defining a strong mathematical formulation for the joint WND and BND problems. To this end, a possible approach is to build upon the pure 0,1 formulations for WND introduced in D'Andreagiovanni et al. (2013) and to extend them to cope with joint WND and BND. This allows for the computation of bounds on the optimal solution values and helps to assess the quality of solutions at hand. *Second*, effective algorithms to solve the unifying model must be developed. Due to the well-known computational difficulty of the problem, new decomposition techniques in conjunction with classical row-and-column generation schemes must be considered. These algorithms could include approximate methods, such as meta-heuristics, to produce quickly good quality solutions that could be used as initial feasible solutions to the problem or, indeed, as final solutions when other methods fail to improve on these. The ability of optimisation algorithms has increased dramatically during the last decades, mainly due to the improved methods and the increased processing powers of personal computers (PCs). (Bixby, 2002) argued that algorithmic and software improvements have played as large a part as processing power[6] when it comes to solving large linear programmes faster. During the period 1987 to 2000, Bixby estimated a speedup increase of six orders of magnitude in solving power, where processing power and memory contributed by three orders of magnitude. The remaining three orders of magnitude is due to an improved algorithm: "A model that might have taken a year to solve ten years ago, can now solve in less than 30 seconds". Recent developments in hybrid, parallel and heterogeneous computing could allow us to overcome the computational challenges encountered when moving towards the integration of the planning problems. For instance, Graphics Processing Units (GPUs) can be exploited as computational power. In addition, most PC-based optimisation algorithms use sequential optimisation methods, which was not an issue while we had an exponential increase in processor clock frequency. However, the modern PC architecture is parallel and heterogeneous—its multiple cores, programmable GPUs open up for parallel computing and heterogeneous computing. Hybrid optimisation methods, as mentioned above, lend themselves well to parallelisation, and these have been successfully applied to solve a number of large scale optimization problems (Brodtkorb et al., 2013). A possible line of research to investigate is the use of heterogeneous computing to plan mobile networks by solving WND and BND jointly.

A final research question concerns the so-called *self-optimising network* (SON). SONs are functions that allow the network to react to fluctuations in traffic demand by adjusting antenna parameters in real time to hand over capacity where needed. Thanks to this, the network can adapt to serve several different demand scenarios. This feature is neglected by current planning models. However, considering SON capabilities in the optimisation model would allow the design of better performing and less costly networks. We believe that one way to incorporate SON capabilities into planning models is by means of *recoverable robust optimisation* models. Recoverable robust optimisation has been

[6]The increase in memory is also beneficial for the algorithms.

recently introduced in (Liebchen et al., 2009), where they consider several input scenarios along with an input algorithm capable of partially recovering deviations from the nominal input. SON capabilities can thus be interpreted as recovering algorithms.

4 CONCLUSIONS

The rapid growth rates in global mobile data traffic impacts the quality of service, and MNOs are finding it increasingly difficult to manage this traffic. They are drastically increasing the number of sites, antennae and modernising existing networks—this is a combinatorial planning problem, where optimisation-based tools could provide substantial assistance. Today however, the planning process is still "manual". Existing optimisation literature have either tackled stylised problems or focused on specific sub-problems. To provide an optimisation-based planning tool to effectively assist planners, the optimisation community needs to work with richer models and algorithms that tackle the overall problem faced by mobile network planners. This requires rethinking current approaches. We need to optimise jointly the location and configuration of new antennae, the configuration of wireless network radio-electrical parameters and the connection to the core network. New models have to be designed, supported by effective algorithms that fully exploit recent improvements both in methods and hardware. The potential benefits of using such optimisation-based planning tools reach further than just MNOs—it will have a positive impact on society as a whole.

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REFERENCES

Aardal K., S.P.M van Hoesel, A. Koster, C. Mannino, A. Sassano (2007), "Models and Solution Techniques for Frequency Assignment Problems", Annals of Operations Research, 153 (1), pp. 79-129.

Amaldi E., A. Capone, F. Malucelli (2003), "Planning UMTS base station location: optimization models with power control and algorithms", IEEE Transactions on Wireless Communications, Vol. 2, No. 5 939-952.

Amaldi E., A. Capone, F. Malucelli, C. Mannino (2006), "Optimization problems and models for planning cellular networks", Handbook of Optimization in Telecommunication, Eds. M. Resende and P. Pardalos, Springer Science.

Atesio (2000) "Atesio GmbH". Available from: http://www.atesio.de/technology/index.html. Accessed 2015-11-02.

Bixby Robert E. (2002). Solving Real-World Linear Programs: A Decade and More of Progress. Operations Research 50(1), pp. 3-15.

Brodtkorb, T. Hagen, G.Hasle and C. Schulz. (2013). *GPU Computing in Discrete Optimization. Part I: Introduction to the GPU.* EURO journal on Transportation and Logistics, 159-186.

Ceria S., C. Mannino, A. Sassano, (1999) Planning Tools Help Designers Optimize Cellular Network, Wireless Design, Available from: http://wirelessdesignonline.com/ doc/planning-tools-help-designers-optimize-cellul-0001. Accessed 2015-11-01.

Charnsripinyo C., D. Tipper (2005), "Topological design of 3G wireless backhaul networks for service assurance", in Design of Reliable Communication Networks, 2005, Proceedings. 5th International Workshop on. IEEE.

Cisco (2015) Visual Networking Index: "Global Mobile Data Traffic Forecast Update 2014–2019" Available from: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html Accessed 2015-10-06.

Cox L. A., J. R. Sanchez (2000), "Designing least cost survivable wireless backhaul networks", Journal of Heuristics, vol. 6, pp. 525-540.

D'Andreagiovanni F., C. Mannino (2009), "An optimization model for WiMAX Network Planning", WiMAX Network Planning and Optimization, Eds. Yan ZHANG, Auerbach Publications.

Dehghan S. (2005), "A new approach", 3GSM Daily 1 (44).

Grøndalen O., O. Østerbø, G. Millstein, T. Tjelta (2015), "On planning small cell backhaul networks", European Conference on Networks and Communications (EuCNC).

Islam M., A. Sampath, A. Maharshi, O. Koymen, N.B. Mandayam (2014), "Wireless Backhaul Node Placement for Small Cell Networks", Annual Conference on Information Sciences and Systems (CISS), 2014.

Liebchen C., M. Lübbecke, R. Möhring, S. Stiller (2009), "The Concept of Recoverable Robustness, Linear Programming Recovery, and Railway Applications", in Lecture Notes in Computer Science, Vol. 5868, pp. 1-27.

Mannino C., F. Rossi F, S. Smriglio (2006), "The network packing problem in terrestrial broadcasting." Operations Research 54(6), pp. 611–626.

Metzger, B. H. (1970), "Spectrum management technique", presentation at 38th National ORSA meeting, Detroit, MI.
NGMN Alliance (2012), "Small cell backhaul requirements", White Paper. Available from: https://www.ngmn.org/uploads/media/NGMN_Whitepaper_Small_Cell_Backhaul_Requirements.pdf. Accessed 2015-10-26.
Rivanda, (2015), "Addresses Ever Increasing Demand" Available from: http://rivada.com/addresses-ever-increasing-demand/. Accessed 2015-10-06.
St-Hilaire M., Shangyun L. (2011), "Comparison of different meta-heuristics to solve the global planning problem of UMTS networks." Computer Networks 55 12, pp. 2705-2716.
Y. Wu and S. Pierre (2003), "Optimization of access network design in 3g networks", in Proc. Canadian Conference on Electrical and Computer Engineering IEEE CCECE 2003, vol. 2, May 4–7, pp. 781–784.

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