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CENIIT Project 08.01 (2008-2013)

Automated Planning and Optimization of Broadband Radio Access Networks

Final Report

1. Background and Motivation

Communication is going wireless. Broadband Radio Access Networks (BRANs), such as 3G/4G cellular, have been under rapid deployment worldwide to deliver wireless mobile Internet, and concepts of 5G are currently being shaped. Project CENIIT 08.01 contributes to this development with optimal design and planning solutions. Planning and Optimization (P&O) play a vital role in the deployment and operation of BRANs. Without proper P&O, BRANs can neither be successfully deployed, nor be successfully expanded. In the initial phase, P&O mainly deals with network dimensioning. While in operation, BRANs have to undergo frequent re-optimization to respond to changes in user demands and service requirements, as well as new business models and opportunities.

P&O of radio access networks is challenging, as there are many network elements, each with a large set of parameters to configure. It is unlikely that a manual tuning approach can deliver satisfactory results in a timely manner. Hence, automated BRAN P&O approaches and tools, outperforming manual approaches in cost, time, and the resulting network performance, are highly desirable.

2. Project Objectives

CENIIT 08.01 develops concepts, models, methods, and tools for automated BRAN P&O. In addition, the project aims at strengthening LiTH's competitiveness in the area. The objectives have been:

- to develop novel approaches for automated P&O of HSDPA/HSUPA (3.5G) and LTE (4G) networks;
- to develop new optimization concepts for wireless networks, in particular wireless mesh networks;
- to implement these approaches to quantitatively demonstrate the benefit of automated P&O;
- to develop modeling framework and approaches for P&O of heterogeneous BRANs;
- to develop effective, time-efficient, and scalable BRAN optimization modules;
- to gain national and international recognition of the research, and to attract external funding to enable the formation and expansion of a strong research group.

Automated P&O of BRANs is interdisciplinary, requiring expertise in wireless communications, optimization, simulation, and computing. It is also intersectorial, as efforts are needed from both industry and academia. CENIIT 08.01 approaches the following long-term objectives in knowledge development:

- to strengthen and integrate competence within group Mobile Telecommunications, ITN, LiTH, and reinforce the group's competitiveness;
- to become a leading group in BRAN P&O;
- to intensify industrial collaboration to form long-term strategic partnership, conduct joint research, and implement transfer of knowledge.

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3. Progress Report

3.1 Project Team

The following people have been partially funded during the project duration (2008-2013):

- Lei Chen, PhD student 2008-2013 (now researcher at Viktoria Institute, Swedish ICT)
- Qing He, PhD student (started Sept. 2011, with Licentiate seminar scheduled Jan. 30, 2014)
- Sara Modarres Razavi[2], PhD student 2008-2014 (now researcher at Ericsson Research)
- Di Yuan, Professor (project leader)

3.2 Highlights

- Scientific publications: 19 articles in international journals, 4 book chapters, and 27 peer-reviewed papers in international conferences. Please see the publication list for details.
- 3 Licentiate Theses [51, 52, 53] by Lei Chen, Sara Modarres Razavi, and Qing He, respectively.
- 2 PhD Dissertations [54, 55] by Lei Chen and Sara Modarres Razavi, respectively
- In 2011 and 2013, the CENIIT project's research area Heterogeneous Networks (HetNets) has been co-funded by two SSF mobility grants for the CENIIT project leader's part-time work at Ericsson Research, substantiating the industrial relevance of CENIIT 08.01 and strengthening the academia-industry knowledge transfer.
- An article [32] received Best Paper Award of IEEE International Conference on Communications (ICC) - the flagship conference of the IEEE Communications Society.
- During 2012-2014, the project leader of CENIIT 08.01 has been awarded four European FP7 grants (as Coordinator), two European Horizon 2020 grants (as Coordinator), two SSF grants (as Principal Investigator), and one grant from the Swedish Research Council (as Principal Investigator), for research proposals within the scope of CENIIT 08.01. The total funding to LiTH of these grants amounts to ~19 MSEK. The achievements are perfectly in line with the CENIIT objective of strengthening the MT group and gaining international recognition.

3.3 Research Achievements

CENIIT 08.01 has conducted research along the following lines.

HSDPA network P&O in UMTS

High speed downlink packet access (HSDPA, aka turbo-3G or 3.5 G) has been a network solution for wide-area broadband radio access. HSDPA differs from UMTS Release 99 (R99) in a number of key technical aspects, necessitating new concepts and methods for automated P&O. CENIIT 08.01 has developed the following results for HSDPA network P&O.

- A comprehensive system model has been developed for coverage planning and antenna configuration for UMTS networks implementing both R99 and HSDPA services. Specific aspects considered include HSDPA performance for users at cell edges, R99 soft handover (SHO), and power sharing between HSDPA and R99.
- Efficient solution approaches and algorithms based on integer linear programming, stochastic search, and two-stage approximation have been developed for the planning problems.

2. Parental leave Jun. 2012 - May 2013.

- Computational experiments of the modeling concepts and solution algorithms for large-scale and realistic planning scenarios have been performed to demonstrate the novelty and effectiveness of the proposed P&O approaches. For the antenna configuration problem, the experiments show that the algorithm developed is able to deliver high-quality solutions for large-city scenarios in minutes.
- An ns-3 HSDPA simulator module has been developed for performance evaluation, and demonstrated via its application for power optimization.

The research has resulted in two journal publications [12, 19], one book chapter [22], and five peer-reviewed articles in IEEE/ACM/IFIP communication conferences [30, 44, 46, 47, 48, 50]. Among them, [22, 50] are joint work with Ericsson Research.

LTE tracking area (TA) reconfiguration and tracking area list (TAL) optimization

For Long Term Evolution (LTE) networks, a key network management concept is automatic reconfiguration - the management system has the intelligence of adapting network configuration to changes and trends in user distribution and demand. A core concept in user mobility management is the use of tracking areas (TAs). A TA is a logical grouping of cells to enable user location information. Optimal layout of TAs has to balance two types of signalling overhead: TA update at uplink when user moves from one TA into another, and paging messages at downlink to place calls to users (having their terminals in idle mode). CENIIT 08.01 develops approaches to deal with system dynamics in TA design. To this end, the project explores two directions being well in line with the self-optimization network (SON) concept in LTE: TA reconfiguration to adapt to changes and trends in user distribution and mobility pattern over time, and optimal design of LTE TA lists (TALs) that have the flexibility of assigning user-individual lists of TAs. The research has led to the following results.

- A re-optimization model for TA reconfiguration to improve signalling overhead while keeping service interruption within an acceptable level, and a solution algorithm based on repeated local search;
- a bi-criteria optimization framework targeting all possible trade-offs (known as Pareto optima) between signalling overhead and reconfiguration cost, along with the development of an effective optimization algorithm;
- insight into the capability of TAL in going beyond the conventional TA approach (in terms of overhead reduction), and an extension of the system model for conventional TA design to TAL optimization, as well as the development of a local search algorithm for optimal TAL design;
- the development of a new TAL scheme using the concept of overlapping TALs for TA update signaling minimization; the scheme does not require prediction of individual user mobility, and admits fast optimization via the solution of a linear programming formulation;
- extension of the overlapping TAL scheme for paging signaling minimization and assessment of its performance;
- a comparative study of static TA versus dynamic TAL, demonstrating the potential of the latter in reducing signaling overhead.

The research has been published in two journal articles [6, 13], six peer-reviewed conference articles [24, 35, 38, 39, 43, 49]. Among them, [13, 38, 39, 43] are joint publications with Ericsson Research. The research of TA reconfiguration and TAL optimization forms the theme of a Licentiate Thesis [52] and a PhD dissertation [55].

LTE inter-cell interference mitigation

The access scheme of LTE downlink is Orthogonal Frequency Division Multiple Access (OFDMA). By OFDMA, intracell interference is not present (unlike CDMA-based networks). Intercell interference, on the other hand, may become a major performance-limiting factor. This is particularly true for users

located at cell edges. Several spectrum reuse concepts, such as fractional frequency reuse (FFR) and soft frequency reuse (SFR), have been proposed for interference control and mitigation. CENIIT 08.01 has carried out research of frequency reuse schemes for intercell interference management in LTE. The progress is summarized below.

- The research has proposed a performance metric to allow for rapid quality assessment of any given frequency reuse solution, and a system framework for optimal FFR for realistic (and hence irregular) cell patterns, providing flexibility in the total number of cell-edge sub-bands as well as the number of sub-bands allocated to each cell-edge zone. A generalization of the concepts to SFR, where cell-edge and cell-centre frequency bands are allowed to partially overlap, has been developed as well.
- The project developed an algorithm optimizing the sub-band allocation pattern for generalized FFR/SFR, and conducted performance evaluations of the algorithm for large-scale OFDMA networks with irregular cell layout. A further extension of the generalized FFR scheme to transmission power, i.e., optimization of both sub-band assignment and power allocation for the cell-edge zones, has been studied.
- A prototype of a fully distributed algorithm for sub-band allocation, using localized cell load information for dynamic FFR, along with its implementation in form of a simulation module including protocol design, have been accomplished.

The research has been disseminated in one journal paper [8] and five peer-reviewed IEEE conference articles [34, 37, 40, 41, 42].

Deployment and resource optimization of heterogeneous LTE networks

Since its mid-term, a research track of CENIIT 08.01 has been planning and optimization of heterogeneous radio network (HetNet) deployment in collaboration with Ericsson Research. The research is motivated by the rapidly evolving wireless technologies and standards that lead to a growing diversity in radio access. HetNets integrate diverse network elements, such as macro and micro base stations, pico and home base stations, relays, etc., that differ significantly in transmission characteristics and capabilities. As the heterogeneity results in a rapid growth in the scale of system configuration options, design variables, and performance objectives, exploring the elements' joint potential is challenging and calls for original research. The efforts within CENIIT 08.01 have made the following achievements:

- theoretical analysis of fundamental properties of a cell-load coupling model, and a case study demonstrating the applicability of the cell-load coupling system model for rapid performance evaluation of network deployment solutions;
- location optimization of pico-cells in HetNets for offloading, using complementary modules of heuristic search and a bounding scheme;
- a framework of HetNet offloading for utilization maximization, and characterization and computation of setting optimal cell load levels;
- range offset optimization of pico-cells with the objective of HetNet load balancing and capacity maximization, by developing optimization algorithms based on principles of design of experiments (DoE) and combining integer programming with Perron-Frobenius theory, respectively, with results that outperform significantly baseline range offset settings;
- a comparative study of standard schemes and new, HetNet-adapted algorithms for cell selection with performance evaluation;

The research has led to two journal articles [1, 10], five peer-reviewed IEEE conference papers [25, 26, 27, 28, 33], and one patent. All papers except [27] are joint publications with Ericsson Research. Among them, [33] received best paper award at IEEE ICC 2012.

New optimization concepts for wireless networks

Since 2010, the research group Mobile Telecommunications (MT), led by the CENIIT project leader, has been part of the Excellence Centre at Linköping-Lund in Information Technology (ELLIIT), funded by a national strategic research grant. Within ELLIIT Area one (Physical Layer of Communications), a research initiative along fundamental performance analysis has been undertaken. The research is co-funded by CENIIT 08.01. Fundamental performance analysis is essential to the design of future generations of high-speed wireless networks. For networks of general topology, numerical computation of performance bounds amounts to solving mathematical optimization problems of fundamental character. Two topics have been investigated by CENIIT 08.01: 1) optimization concepts and scalable algorithms for maximum link admission in wireless networks with general topology, 2) analysis of the capacity gain of interference cancellation and cooperative transmission. Research pursuing the topics is original in opening up new landscape of capacity optimization of wireless communications. The following progress has been made:

- computationally effective solution of maximum link admission, based on advanced use of cutting planes of cover inequalities; the solution scheme outperforms all previously known methods in reaching global optimality, and enables fundamental performance studies of large-scale systems;
- complexity result and integer programming for performance assessment of single-stage interference cancellation via collaborative rate adaptation, and simulation experiments demonstrating the effectiveness of the approach;
- optimality conditions and a unified algorithmic framework for scheduling in wireless networks; the conditions and algorithm are generally applicable, without restriction to any particular radio technology or network type;
- complexity analysis and optimization approaches for the problem of maximum link admission with successive interference cancellation, gaining insights into the potential gain of interference cancellation in enhancing capacity.

The research has been published in four journal articles [2, 5, 14, 15] and three conference papers [29, 32, 36].

A topic being closely related to the above work is the development of optimization concepts for performance engineering of wireless mesh-type networks (WMNs). Performance engineering of WMNs necessities new optimization models and approaches for interference avoidance, resource allocation, and routing. The CENIIT project develops cross-layer optimization models for WMNs, with the following research achievements:

- optimization models and solution algorithms for analyzing the gain of cooperative transmission in WMNs in comparison to the classic hop-by-hop forwarding scheme;
- an integer programming method for joint routing and scheduling in WMNs under the max-min fairness metric, and its performance evaluation via simulation;
- new computational approaches for optimizing compatible sets in WMNs;

The research has been disseminated in three journal articles [3, 4, 16], one book chapter [20], and one conference paper [31].

Additional research topics

Wi-Fi network planning has been a complementary topic in CENIIT 08.01. The research has dealt with the development of optimization models for access point (AP) location and channel assignment, capturing the medium contention behavior of the Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) protocol in Wi-Fi networks. The work has developed solution algorithms based on integer programming techniques, in particular column generation and branch-and-cut. The research has been conducted

jointly with colleagues at Dipartimento di Elettronica e Informazione, Politecnico di Milano, Italy, Zuse Institute Berlin (ZIB), Germany, and Ericsson Research. The research is published in one journal article [18], one book chapter [23], and one peer-reviewed conference article [45].

Another complementary topic has been models and algorithms for constructing minimum-energy broadcast topology in wireless ad hoc networks. The CENIIT project has developed new integer programming models for range assignment, the problem of determining the power ranges of radio devices to provide strong connectivity in a wireless network, and derived highly efficient solution algorithm for the topology problem of constructing a single broadcast tree. The work, carried out in collaboration with the University of Bergen, Norway, has been published in a journal paper [7] and a book chapter [21].

In the area of resource allocation in OFDMA, the CENIIT project has international research collaboration with Institute for Infocomm Research, Singapore. The joint research has developed new solution schemes for optimal power allocation for multi-user and multi-channel OFDMA systems, with one journal publication [9].

Within a collaboration with IDA, LiTH, analysis of routing in delay-tolerant wireless networks has been performed. The joint work has resulted in a journal publication [11].

In addition to the above, the CENIIT project hosted a visiting researcher from Telecom Bretagne, France. The visit has led to the study of a complementary topic in service distribution optimization in the Internet. The study is published in [17].

4. Contribution to PhD Study

An important aspect of CENIIT-funded projects is the contribution to PhD studies. Within CENIIT 08.01, three PhD students, Lei Chen, Sara Modarres Razavi, and Qing He, have been partially funded for their PhD study, with the following achievements:

4.1 Licentiate Theses

- L. Chen. *Coverage Planning and Resource Allocation in Broadband Cellular Access: Optimization Models and Algorithms*. Linköping Studies in Science and Technology, Theses, No. 1454, Dec. 2010.
- S. Modarres Razavi. *Tracking Area Planning in Cellular Networks: Optimization and Performance Evaluation*. Linköping Studies in Science and Technology, Theses, No. 1473, Apr. 2011.
- Q. He. *Revisiting Optimal Link Activation and Minimum-Time Scheduling in Wireless Networks*. Linköping Studies in Science and Technology, Theses, No. 1695, 2014. (The Licentiate seminar is scheduled to take place in Jan. 2015).

4.2 PhD Dissertations

- L. Chen. *Performance Engineering of Mobile Broadband: Capacity Analysis, Cellular Network Optimization, and Design of In-Building Solutions*. Linköping Studies in Science and Technology, Dissertations, No. 1504, Apr. 2013.
- S. Modarres Razavi. *Planning and Optimization of Tracking Area for Long Term Evolution Networks*. Linköping Studies in Science and Technology, Dissertations, No. 1588, May 2014.

The success of CENIIT 08.01 in fostering PhD education is also demonstrated by the career development of L. Chen and S. Modarres Razavi, who are now working as researchers at Viktoria Institute, Swedish ICT, Göteborg, and Ericsson Research, Linköping, respectively.

5. Collaborations

5.1 Industrial Collaboration

CENIIT 08.01 has been shaped for strong industrial relevance. The bulk of industrial collaboration is carried out with Ericsson Research, Sweden. In 2011 and 2013, the project leader of CENIIT 08.01 worked part time at Ericsson Research, with the effect of reinforcing the industrial relevance of the CENIIT project. The industrial collaboration has resulted in the following joint publications:

- three journal articles [1, 10, 13]
- one book chapter [22]
- eight peer-reviewed IEEE conference articles [25, 26, 28, 33, 38, 39, 43, 50]

The CENIIT group participated in European FP7 Marie Curie Industry-Academia Partnerships and Pathways (IAPP) project IAPP@RANPLAN (2009-2012). In the IAPP project, industrial collaboration has taken place via researcher mobility actions within the CENIIT 08.01 research area of HSPA radio network P&O.

5.2 Collaboration within LiTH and with Lund University

The research of developing new optimization concepts for wireless networks has been conducted in collaboration with Department of Electrical Engineering (ISY), LiTH, and Department of Electrical and Information Technology (EIT), Lund University, with three joint journal publications [3, 4, 5] and two conference papers [31, 36].

The MT group has previously had collaboration with CENIIT project 00.11, “Fault Tolerance in Real-time Distributed Systems”, led by Prof. Simin Nadjm-Tehrani (IDA, LiTH). Within CENIIT 08.01, joint work has been conducted in the common interest area of delay-tolerant wireless networking with one journal publication [11].

5.3 International Academic Collaboration and European Research Networks

The CENIIT project has had international collaboration with the following academic sites with joint publications. These collaborations not only strengthen the impact of the CENIIT project, but also contribute to the international profile of Linköping University.

- Telecom Bretagne, France.
- Zuse Institute Berlin (ZIB), Berlin-Dahlem, Germany.
- University of Wurzburg, Germany.
- Dipartimento di Elettronica e Informazione, Politecnico di Milano, Italy.
- Department of Informatics, University of Bergen, Norway.
- Institute for Infocomm Research, Singapore.
- Institute for Systems Research, University of Maryland, USA.

The CENIIT project group has been participating in four European Cooperation in the field of Scientific and Technical Research (COST) actions in areas of interest to the CENIIT project, enhancing the visibility of the CENIIT group and generating networking effects: 1) COST 293: Graphs and Algorithms in Communication Networks, 2) COST 2100: Pervasive Mobile & Ambient Wireless Communication, 3) COST IC0902: Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks, and 4) COST IC1101: Optical Wireless Communications: An Emerging Technology.

6. Publications

6.1 Project Publications

International Journal Articles

[1] I. Siomina and D. Yuan. Optimizing small cell range in heterogeneous and load-coupled LTE networks. *IEEE Transactions on Vehicular Technology*. DOI: 10.1109/TVT.2014.2338613, 2014.

[2] V. Angelakis, A. Ephremides, Q. He, and D. Yuan. Minimum-time link scheduling for emptying wireless systems: solution characterization and algorithmic framework. *IEEE Transactions on Information Theory*, 60:1083-1100, 2014.

[3] Y. Li, M. Pioro, D. Yuan, and J. Su. Optimizing compatible sets in wireless networks through integer programming. *EURO Journal on Computational Optimization*, 2:1-15, 2014.

[4] M. Pioro, M. Zotkiewicz, B. Staehle, D. Staehle, and D. Yuan. On max-min fair flow optimization in wireless mesh networks. *Ad Hoc Networks*, 13:134-152, 2014

[5] D. Yuan, V. Angelakis, L. Chen, E. Karipidis, and E. G. Larsson. On optimal link activation with interference cancellation in wireless networking. *IEEE Transactions on Vehicular Technology*, 62:939-945, 2013.

[6] S. Modarres Razavi and D. Yuan. Mitigating signaling congestion in LTE location management by overlapping tracking area lists. *Computer Communications*. 35: 2227-2235, 2012.

[7] D. Yuan and D. Haugland. Dual decomposition for computational optimization of minimum-power shared broadcast tree in wireless networks. *IEEE Transactions on Mobile Computing*. 11:2008-2019, 2012.

[8] L. Chen and D. Yuan. Generalizing and optimizing fractional frequency reuse in broadband cellular radio access networks. *EURASIP Journal on Wireless Communications and Networking*. 2012:230, 2012.

[9] J. Joung, K.-C. Ho, D. Yuan, and S. Sun. Energy efficient network-flow-based algorithm for multiuser multicarrier systems. *IET Networks*, 1:66-73, 2012.

[10] I. Siomina and D. Yuan. Analysis of cell load coupling for LTE network planning and optimization. *IEEE Transaction on Wireless Communications*. 11:2287-2297, 2012.

[11] E. Kuiper, S. Nadjm-Tehrani, and D. Yuan. A framework for performance analysis of geographic delay-tolerant routing. *EURASIP Journal on Wireless Communications and Networking*. 2012:184, 2012.

[12] L. Chen and D. Yuan. Coverage planning for optimizing HSDPA performance and controlling R99 soft handover. Accepted by *Telecommunication Systems*. 51:53-64, 2012.

[13] S. Modarres Razavi, D. Yuan. F. Gunnarsson, and J. Moe. Performance and cost trade-off in tracking area reconfiguration: a Pareto-optimization approach. *Computer Networks*. 56:157-168, 2011.

[14] V. Angelakis, L. Chen, and D. Yuan. Optimal and collaborative rate selection for interference cancellation in wireless networks. *IEEE Communications Letters*, 15:819-821, 2011.

[15] A. Capone, S. Gualandi, L. Chen, and D. Yuan. A new computational approach for maximum link activation in wireless networks under the SINR model. *IEEE Transactions on Wireless Communications*, 10:1368-1372, 2011.

[16] A. Capone, S. Gualandi, and D. Yuan. Joint routing and scheduling optimization in arbitrary ad hoc networks: comparison of cooperative and hop-by-hop forwarding. *Ad Hoc Networks*. 9:1256-1269, 2011.

[17] J. Leblet, Z. Li, G. Simon, and D. Yuan. Optimal network locality in distributed virtualized data-centers. *Computer Communications*, 34:1968-1979, 2011.

[18] E. Amaldi, S. Bosio, Federico Malucelli, and D. Yuan. Solving nonlinear covering problems arising in WLAN design. *Operations Research*. 59:173-187, 2011.

[19] L. Chen and D. Yuan. Solving a minimum-power covering problem with overlap constraint for cellular network design. *European Journal of Operational Research*, 203:714-723, 2010.

Book Chapters

[20] A. Capone, I. Filippini, S. Gualandi, and D. Yuan. Resource optimization in multi-radio multi-channel wireless mesh networks. In: M. Conti (editor), Mobile Ad Hoc Networking: The Cutting Directions, IEEE & Wiley, 2012.

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Kennington, E. Olinick, and D. Rajan, editors, *Wireless Network Design: Optimization Models and Solution Procedures*, Springer International Series in Operations Research and Management Science, Springer, pp. 219-246, 2011.

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Peer-reviewed Conference Articles

[24] S. Modarres Razavi and D. Yuan. Reducing signaling overhead by overlapping tracking area list in LTE. *Proceedings of 7th IFIP Wireless and Mobile Networking Conference*, 2014.

[25] I. Siomina and D. Yuan. On optimal load setting of load-coupled cells in heterogeneous LTE networks. *Proceedings of IEEE International Conference on Communications (ICC)*, 2014.

[26] I. Siomina and D. Yuan. Optimization approaches for planning small cell locations in load-coupled heterogeneous LTE networks. *Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Communications (PIMRC)*, 2013.

[27] K.-C Ho, D. Yuan, and S. Sun. Data offloading in load coupled networks: solution characterization and convexity analysis. *Proceedings of 2nd International Workshop on Small Cell Wireless Networks (SmallNets) at IEEE International Conference on Communications (ICC)*, 2013.

[28] Z. Chao, V. Angelakis, D. Yuan, and B. Timus. Evaluation of cell selection algorithms in LTE-advanced relay networks. *Proceedings of IEEE 18th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, 2013.

[29] Q. He, V. Angelakis, A. Ehpremides, and D. Yuan. Revisiting minimum-length scheduling in wireless networks: an algorithmic framework. *Proceedings of International Symposium on Information Theory and its Applications (ISITA)*, 2012.

[30] A. Matinrad, V. Angelakis, and D. Yuan. An ns-3 HSPA network simulator with application to evaluating a base station removal algorithm. *Proceedings of IET International Conference on Wireless Communications and Applications (ICWCA)*, 2012.

[31] Y. Li, M. Pioro, J. Su, and D. Yuan. On joint optimization of link rate assignment and transmission scheduling in wireless mesh networks. *Proceedings of IEEE 15th International Telecommunications Network Strategy and Planning Symposium (NETWORKS 2012)*.

[32] V. Angelakis, A. Ephremides, Q. He, and D. Yuan. On emptying a wireless network in minimum Time. *Proceedings of IEEE International Symposium on Information Theory (ISIT)*, 2012.

[33] I. Siomina and D. Yuan. Load balancing in heterogeneous LTE: range optimization via cell offset and load-coupling characterization. *Proceedings of IEEE International Conference on Communications (ICC)*, 2012.

[34] V. Angelakis, M. Sajid, I. Siddiqui, and D. Yuan. A distributed, load-aware, power and frequency bargaining protocol for LTE-based networks. *Proceedings of 2nd IEEE International Workshop on Smart Communication Protocols and Algorithms (SCPA)*, Ottawa, Canada, June 2012.

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[36] E. Karipidis, E. G. Larsson, and D. Yuan. Mixed-integer linear programming framework for max-min power control with single-stage interference cancellation. *Proceedings of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2011.

[37] V. Angelakis, L. Chen, and D. Yuan. A fully decentralized and load-adaptive fractional frequency reuse scheme. *Proceedings of Annual Meeting of the IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS)*, 2011.

[38] F. Gunnarsson, J. Moe, S. Modarres Razavi, and D. Yuan. Dynamic tracking area list configuration and performance evaluation in LTE. *Proceedings of IEEE GLOBECOM Workshop on Seamless Wireless Mobility 2010*, 2010.

[39] F. Gunnarsson, J. Moe, S. Modarres Razavi, and D. Yuan. Exploiting tracking area list for improving signaling overhead in LTE. *Proceedings of IEEE Vehicular Technology Conference (VTC Spring 2010)*, 2010.

[40] L. Chen and D. Yuan. Enhanced fractional frequency reuse for large-scale OFDMA networks with heterogeneous cell layout: optimization and performance evaluation. *Proceedings of IEEE International Conference on Communication Systems (ICCS 2010), 2010*.

[41] L. Chen and D. Yuan. Generalized frequency reuse schemes for OFDMA networks: optimization and comparison. *Proceedings of IEEE Vehicular Technology Conference (VTC Spring 2010)*, 2010.

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[43] F. Gunnarsson, J. Moe, S. Modarres Razavi., and D. Yuan. Optimizing the tradeoff between signaling and reconfiguration: A novel bi-criteria solution approach for revising tracking area design. *Proceedings of IEEE Vehicular Technology Conference (VTC Spring 2009)*, 2009.

[44] L. Chen and D. Yuan. Fast algorithm for large-scale UMTS coverage planning with soft handover consideration. *Proceedings of the 5th ACM International Wireless Communications and Mobile Computing Conference (IWCMC 2009)*, 2009.

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Licentiate Theses

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[52] S. Modarres Razavi. T*racking area planning in cellular networks: optimization and performance evaluation*. Linköping Studies in Science and Technology, Theses, No. 1473, 2011.

[53] Q. He. R*evisiting Optimal Link Activation and Minimum-Time Scheduling in Wireless Networks*. Linköping Studies in Science and Technology, Theses, No. 1695, 2014.

PhD Dissertations

[54] L. Chen. *Performance Engineering of Mobile Broadband: Capacity Analysis, Cellular Network Optimization, and Design of In-Building Solutions*. Linköping Studies in Science and Technology, Dissertations, No. 1504, April 2013.

[55] S. Modarres Razavi. *Planning and Optimization of Tracking Area for Long Term Evolution Networks*. Linköping Studies in Science and Technology, Dissertations, No. 1588, May 2014.