CHALLENGES IN MOBILE NETWORK OPERATION: TOWARDS SELF-OPTIMIZING NETWORKS

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ABSTRACT

This paper reviews current status and trends in the application of self-organizing principles to advanced wireless networks, such as 3GPP Long-term Evolution (LTE). The transfer of research results and concepts to real-world networks imposes additional constraints and requirements, which open a multitude of interesting new fields for applied research. Particular challenges include defining appropriate assessment criteria, evaluation methodology, as well as a variety of interrelations between use cases with conflicting goals and mutual parameter dependencies yielding nonclosed-form problems. Furthermore only partial, error-prone and potentially inconsistent information is available. Additional challenges include minimization of overhead, stability, and convergence issues, in particular for decentralized solutions.

Index Terms— Self-organizing networks, self-optimization, LTE.

1. INTRODUCTION

Self-organizing networks (SON) is a research field with numerous applications to different types of networks (NWs). Even in the specific case of self-organization aspects in wireless NWs, research areas range from advanced cognitive radio concepts to very concrete problems in standardization and implementation. The scope of this paper is in the latter area, summarizing current status and research issues in particular with application to 3GPP Long-term Evolution (LTE) and similar wireless NWs.

Major drivers for SON in wireless NWs include the quest to reduce operational expenditures (OPEX) by automating functionality currently performed manually or with extensive human work time (in all areas such as deployment, operation or maintenance). Furthermore SON also allows reducing capital expenditures (CAPEX) by optimized use of network elements (NEs) and physical resources, and prolonging equipment lifetime. Therefore the same coverage, capacity, and quality can be obtained with less investment in NEs, or those performance measures can be improved, thus allowing increased capacity, higher subscriber loyalty, and reduced failure events. However, there is no clear way to proceed from such high-level goals, business strategies, and policies to a concrete setting of hundreds of technical parameters of each NE.

With the ongoing trend to higher NE densities (due to higher carrier frequencies, higher bandwidth and data rates, residential and indoor nodes) and increasing complexity of each NE, self-organization of wireless NWs becomes a key component for efficient NW operation.

2. STATUS AND TRENDS IN SON FOR WIRELESS NETWORKS

The adoption of a flat architecture is a major new paradigm in wireless NWs (e.g. comparing LTE to UMTS). It has lead to the fact that many radio functions formerly performed by central entities are now located in the NEs, i.e. eNBs in case of LTE. Thus decentralized processing and direct communication of the NE has become an important method in the user and control plane. This has obviously also impact on the operation, administration, and maintenance (OAM) system, which is still mainly based on a centralized and layered approach as in 3G [1]. Therefore integrated codesign of architecture, management, and radio part of the system is required.

Self-organization of wireless NWs can be differentiated into self-configuration (covering pre-operational phases of NEs, such as planning and deployment), self-optimization (optimization during operational phase), maintenance and self-healing (recovering from faults) [2]. Within each of these areas, several use cases with individual goals and requirements exist [3][4][5].

Different SON use cases will be relevant at different times of NW operation, e.g. during initial roll-out, early phases of operation, or operation of a mature NW with high load. In general use cases related to self-configuration and coverage are most important in the earlier phases, whereas qualityand capacity-based use cases will be in the focus later. Currently SON functions related to self-configuration of new NEs and automatic neighbor relation functions are standardized for LTE in Rel. 8. Furthermore work has been done on related signaling, e.g. load information over X2 interface. It can be expected that during 2009 (Rel. 9) this work will be continued and additional use cases relevant in the network roll-out phase will be investigated.

Furthermore new features of next-generation wireless NWs will also have implication on SON and add new use cases or requirements/constraints to existing ones. The SON-related requirements for LTE-Advanced [6] are energy efficiency of NW and terminals, SON in heterogeneous and mass deployments, and avoiding costly drive tests to detect problems and sound the NW coverage and performance. Potential new features and scenarios in the scope of LTE-Advanced, that have significant impact on NW operation and SON use cases, are shortly discussed in the following.

The so-called Home eNBs (HeNBs) are base stations with small transmit power that are deployed by private persons, similar to WLAN access points. It is obvious that such an uncoordinated mass deployment of small NE requires "plugand-play", i.e. self-configuration with minimum involvement of any centralized entity. Furthermore mobility between traditional (macro) NW and HeNB needs to be solved for open and closed subscriber group cases. A prerequisite for co-channel deployment with the macro NW would be the capability to prevent any harm due to interference in a self-organizing way.

The use of in-band relays and repeaters can improve coverage and capacity, thus management of these new network nodes is a relevant use case in the future. Both, HeNBs and relays will require the handling of larger and more dynamic NW topologies and bring new aspects in fault management, as they might temporarily be switched off (due to interference, capacity, or energy saving reasons), moved to other places, and operate with less reliability.

Enhanced MIMO processing will benefit from control and SON coordination of MIMO mode selection in order to adapt to the actual load, spatial user distribution, mobility, terminal capabilities, and manage changing interference conditions due to spatial processing, etc., see [7][8].

Another research field capable of delivering significant gain is flexible spectrum use in contiguous and non-contiguous spectrum allocations, within and across NWs and technologies, as well as on different time scales and levels of coordination [8].

3. BASIC ALTERNATIVES FOR SON SOLUTIONS

Centralized, decentralized, and localized solutions or combinations thereof, so-called hybrid SON solutions are in discussion [1]. Although the best solution needs to be derived case-by-case, some general guidelines for selection of an appropriate solution type are given in Figure 1. With increasing number of NEs involved and slower timescale of the optimization process centralized SON functionalities become more appropriate. Decentralized solutions locate the SON functionality in the NEs and can be further differentiated into the distributed case, where the SON functionality of multiple NEs need to collaborate and into the localized case, where the problem can be solved by a single NE without the need to communicate or coordinate. Please note, that typically one NE controls multiple radio cells.

A discussion of general design principles for self-organization in communication NWs is provided in [9], stressing the importance to research decentralized algorithms that are able to achieve global goals and to exploit implicit coordination.

4. CHALLENGES TO MAKE SON A REALITY

Although each use case is a valid research object in itself, we will focus here on high-level challenges that apply to multiple use cases, such as interrelation of use cases and parameters, availability, consistency and reliability of information, algorithm design, stability, convergence, and overhead, as well as evaluation aspects.

4.1. Interrelation of Use Cases and Parameters

Careful analysis of individual use cases show that many of them adapt the same parameters [1], however partly with conflicting goals. For example although the best HO quality would be achieved by immediately switching to the cell with better signal level, this strategy will lead to excessive ping-pong handover due to signal fluctuations (e.g. fading). Additionally load balancing goals will impact the setting of HO parameters. Thus the SON algorithm must combine multiple and partly conflicting goals into one target function based on operator policy [1]. Also optimization parameters are interconnected yielding non-linearity and non-closed form expressions, as exemplified by the mutual dependency of load and SINR in [10].



Figure 1: General guidelines for SON solution approach

4.2. Availability, Consistency and Reliability of Information

Especially with the advent of decentralized approaches, the availability, consistency and reliability of information in the different NEs will dictate how much of theoretical gain can be captured in real-world application. Improving these quantities entails signaling overhead and delay, and a suitable trade-off needs to be investigated.

In principle decentralized solutions to neighbor avoidance problems (e.g. allocation of scrambling codes, physical cell IDs, etc.) are available [11]. However, the fact that a real system might have only partial or error-prone knowledge of the existing neighbors and might not be able to detect all existing collisions adds completely new aspects to the problem.

Another challenge is to enable scattered deployment of different vendors' equipment. The associated standardization and fixing of solutions, procedures and measurements must be balanced with the requirement to allow permanent enhancement of the system and competition by vendorspecific concepts and algorithms.

4.3. Algorithm Design

Incomplete and partly erroneous information and the fact there is no clear mapping from a large vector of input data to the root cause of a problem, or a promising strategy to improve the situation lead us towards a probabilistic/statistical approach. Full search approaches are impossible due to the large parameter space. Trial-and-error in a live NW is prohibitive due to the risk of negative performance impact, effort and required time, since the need to collect sufficient performance statistics to understand the impact of the previous change will require long update intervals.

It is thus obvious that the transfer of existing concept and algorithms (e.g. based on heuristics, self-learning, fuzzy logic, game theory, or genetic algorithms, just to name a few) from research to application provides a multitude of interesting research tasks [12][13][14][15].

4.4. Stability, Convergence, and Overhead

An important requirement of SON algorithms is stability even under the constraints of partial and error-prone information and in dynamic NW topologies (cf. insertion of new NEs, temporally switching off NEs, or faults). Furthermore stability and convergence needs to be insured in the context of various other adaptation mechanisms operating on different time scales, like channel allocations, power control, link adaptation, scheduling, admission control and further RRM functions [16]. Overhead and delay will put limits on availability and reliability of information for the SON algorithm, as discussed in Section 3.4. Therefore fast convergence and the capability of the algorithm to localize required impact and signaling of changes to small parts of the NW are crucial to limit the signaling load in particular of distributed algorithms. [11]. As an example, if a new NE is inserted, it should obtain valid synchronization and physical cell ID within few iterations and without needing information from or causing changes to the parameters of many other NEs.

4.5 Evaluation Aspects

A quantification of the savings due to individual SON use cases is very difficult. Apart from the technical performance improvement, they depend very much on the economics, and cost models. Obviously it is hard to derive a final quantitative metric to capture all these aspects, in particular as the costs are confidential and highly dependent on the deployment scenario, region, strategy and work flows. Nevertheless some factors impacting the benefits can be quantified better, in particular the performance improvement (wrt. coverage, capacity, energy efficiency) per application of a SON feature and the periodicity / time share a particular improvement can be exploited.

Traditionally system-level simulations are targeted either towards evaluation of radio performance to help decisions in system design or towards real NW planning tasks. Whereas the former typically rely on simple regular NW topologies (such as hexagonal or Manhattan grids) and homogeneous user and traffic distributions, the latter build on data bases containing information on terrain height, land use, building data, user distribution and traffic intensity of a particular area.

System design for SON somehow falls between the two categories. On the one hand, it is impossible to simply reuse the homogeneous performance-related system design evaluation assumptions, since one of the central goals of SON, namely to follow long-term changes in spatial and temporal user and traffic distributions, cannot be captured.

On the other hand, it is prohibitive to try to do SON system design based on highly complex investigations in particular real-world NW scenarios. Such investigations require expensive data bases (and partly confidential insight in existing NWs), and complex simulators. Furthermore they lack generality. Therefore to avoid the risk to optimize to a particular scenario, many different locations would need to be simulated, at the expense of extremely high computational requirements and simulation time.

A starting point to derive a "feasible and conclusive" evaluation methodology for SON could be to enhance agreed system design evaluation assumptions as required for the investigated use case. For example simple models to simulate inhomogeneous spatial and temporal distributions of users are required for load balancing simulations.

Use cases related to alignment or avoidance of neighbors (e.g. synchronization, re-use management of physical resources) will need to be tested also in irregular or even non-planar NWs in order to avoid artifacts such as optimization to a particular regular NW design with a constant number of neighbors.

Also performance metrics of radio performance oriented system-level simulations are not suitable to judge and compare different SON concepts and therefore require adaptation and augmentation [2]. For example simple SINR distributions are no longer conclusive in the case of inhomogeneous cell load. The widely used assumption of full buffer traffic will not allow to investigate load balancing, and the impact of inhomogeneous network topology needs to be considered. A basic mathematical framework for quantitative investigation of optimizing coverage and capacity, load balancing and energy savings based on a satisfied user criterion is presented in [10].

Apart from defining SON evaluation scenarios, parameters and performance metrics, SON simulator design itself is a challenging task. Typically the SON adaptations use longterm statistical data as input, react on slow changes in the NW, and adjust parameters in long time intervals, e.g. minutes, hours, or even days depending on the use case considered. Nevertheless SON is interacting with the existing adaptation mechanism and control loops that act on much faster time scales. For example, changes of the handover (HO) parameters would only occur after careful examination of HO statistics, the evaluation of the performance of this adaptation, however, needs to capture also fast fading effects during HO.

It is obvious that simulating such long real-time periods with high temporal resolution would yield prohibitive simulation complexity. Therefore advanced, event driven or scalable, multi-level simulation techniques are required. Furthermore the appropriate simplifications in lower layers of the radio systems need to be investigated, as well as delay and error models for the input information (measurements, PM statistics, counters, alarms, etc.) used by the SON algorithms.

4. CONCLUSION

Making self-organization and self-optimization a reality in future wireless networks is a promising field for applied research, since networks become increasingly complex, while deployment as well as operation costs need to be reduced. Target functions, performance metrics, and evaluation methodology need to be defined. Algorithms need to provide fast stability, convergence even when operating on partial and error-prone information.

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