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Embedding Multiple Self-Organisation Functionalities in Future Radio Access Networks

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Abstract— **Wireless network operators today allocate considerable manual effort in managing their networks. A viable solution for lowering the manual effort is to introduce self-organisation functionalities. In this paper we discuss the challenges that are encountered when embedding multiple self-organisation functionalities into an overall self-organisation concept for future wireless networks. We foresee that there will most likely be a need of a rather complex coordination mechanism for handling multiple self-organisation functionalities in future wireless access networks.**

Keywords-LTE; Self-Organisation; Self-Configuration; Self-Optimisation; Self-Healing; Coordination; Multi-Objective Optimisation; E-UTRAN

I. INTRODUCTION

Wireless network operators today have considerable manual effort in planning, configuring, optimising, and maintaining their wireless access networks. These efforts consume a great part of their operational expenditures (OPEX). Currently, the standardisation body 3rd Generation Partnership Project (3GPP) is finalising the standardisation of the UMTS successor named as Evolved UTRAN (E-UTRAN), commonly known as Long Term Evolution (LTE). An important E-UTRAN requirement from the operators' side is a significant reduction of the manual effort in the deployment, configuration and optimisation phases for this future wireless access system. A viable method for achieving this requirement is the introduction of self-organisation functionalities into the E-UTRAN. This possibility is actively promoted by the wireless operator consortium Next Generation Mobile Networks (NGMN) [1][2]. 3GPP is also adopting the self-organisation concept [3][4].

Several publications address optimisation of wireless access networks, e.g., capacity and coverage balancing [5][6], code planning for UMTS [7][8], base station location [9], and admission control [10]. Some papers study self-configuration of neighbour cell lists, e.g., [11][12]. Self-organisation in LTE is becoming a hot topic and efforts carried out within 3GPP include interference coordination [13], handover (HO) parameter optimisation [14], load balancing [15], and cell outage compensation [16]. All of these contributions, however, focus on standalone self-organisation functionalities and, as such, the integration of several functions is not considered.

The main objective of the European FP7 research project SOCRATES [17]-[20] is to develop dedicated solutions, methods and algorithms for self-organisation comprising self-configuration, optimisation, and healing in 3GPP E-UTRAN. The SOCRATES vision on self-organising networks (SON) is as follows: at network deployment phase the self-configuration functions can be used for configuring the important parameters of network elements. The self-optimisation functions in the network elements continuously perform measurements and use these measurements for an optimisation loop that adapts to the current propagation and traffic conditions and extracts the most out of the available resources. At incidental changes, e.g., network element outage, the self-healing functionalities help to maintain the coverage and acceptable quality of service level.

The SOCRATES concept envisages multi-functional self-organisation, i.e., optimising several goals/objectives simultaneously. The main focus of this paper is to highlight the challenges when embedding multiple self-organisation functionalities into the overall self-organisation concept for future wireless networks. We show that there is most likely a need for coordination between the self-organisation functionalities and illustrate the complexity of such a mechanism.

The paper is organised as follows: the description of self-organisation functionalities by means of use cases is presented in Section II. Section III presents in detail how parameters influenced by several self-organisation functions are grouped into so-called functional parameter groups. The dependencies and interactions between self-organisation functionalities, and triggers are elaborated in Section IV. In Section V a framework is presented for coordination and conflict resolution between the different self-organisation functionalities. Section VI draws conclusions for further developments.

II. USE CASES

Use cases are an established means of describing what a solution to a particular problem shall achieve. Within the SOCRATES project, a set of twenty-four use cases has been identified focusing on self-organisation in 3GPP E-UTRAN [18]. For each use case a description is given regarding its objectives, input triggers, interaction with other use cases, actions to be taken, and the desired reaction to the problem. There are use cases for self-configuration, self-optimisation, and self-healing functionalities. The use cases have been selected based on the expected gain, feasibility, originality, and the time-scale of the use cases [19]. The latter refers to at what phase in the LTE network deployment the particular self-organisation functionality is expected to be useful. The motivation here is to prioritise use cases that might be desired from the early phase of the LTE network deployment.

Two examples of self-configuration use cases are the automatic generation of default parameters for network element insertion and intelligently selecting site locations. They aim at automatic parameter configuration in a plug and play fashion for newly inserted network elements, where the parameter values are better than simple default values. Furthermore, the network elements affected by the new network node are automatically reconfigured as well.

The self-optimisation use cases aim at continuous optimisation of the network performance based on the performance targets set by the wireless operator and current network conditions. For example, self-optimisation of radio resource management (RRM) algorithms, e.g., admission control and scheduler, means that the parameters and thresholds used in these algorithms are dynamically adjusted according to the operator policies and network conditions such as spatial traffic distribution, traffic mix, and drastic traffic load level changes. The self-optimisation use case definitions and descriptions identify also the envisaged interactions among different self-optimisation functionalities. For example, the self-optimised load balancing functionality will adjust the HO parameters in order to transfer traffic towards the neighbour cells if load imbalance is detected. At the same time these HO parameters are dynamically adjusted by the self-optimised HO functionality that aims at reducing HO failures.

The self-healing use cases (e.g., cell outage detection and compensation) describe how to maintain the network performance (in terms of coverage and quality) on an acceptable level in situations where the network conditions have drastically changed, e.g., due to hardware failures. In these situations the self-healing functionalities first have to detect the change in the network conditions and then take the appropriate actions in order to optimise the network.

III. FUNCTIONAL PARAMETER GROUPS

In situations where the network parameters can be adjusted by two or more self-organising functionalities these adjustments have to be coordinated in order to avoid oscillating and unstable system behaviour. This section describes the classification of different radio parameters into so-called functional parameter groups. The outcome of the grouping allows the identification of self-organisation functionalities and parameters that do not need to be coordinated. As we shall see, the majority of the parameters fall in the same group, thus, it is likely that the majority of self-organisation functionalities must be coordinated.

In the following, the term *radio parameter* refers to any parameter that is tuneable and that can be set by different self-organisation functionalities, e.g., HO parameters, pilot power, and antenna tilt. The concept of functional parameter groups is illustrated in Fig. 1, where three goals are defined together with a set of parameters that contribute to the satisfaction of each goal. A parameter can affect multiple goals, e.g., transmit power affects both coverage and inter-cell interference. If a parameter affects multiple goals, then these goals and their respective parameters fall into the same group. The functional parameter groups have the important property that there is no coupling between the parameters of one group and the parameters of other groups. As such, there is no need of coordination between the parameters of different groups. There is, of course, a need of coordination among the parameters in the same group. By studying the use cases presented in Section II (more details can be found in [18]) a list of goals and the corresponding parameters is obtained, see Table I. In order to facilitate the derivation of the functional parameter groups, parameters that are related, e.g., resource block transmit power, total cell transmit power, and pilot transmit power, are gathered under one single notation, e.g., transmit power. Similarly, antenna parameters comprise antenna tilt, azimuth, and MIMO parameters.

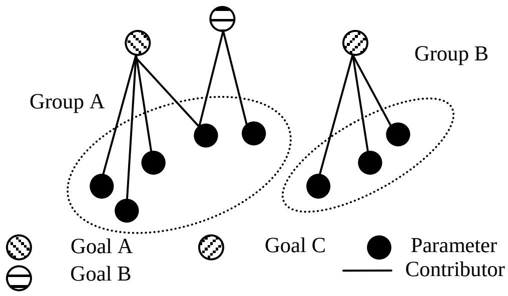

Figure 1. Illustration of the functional parameter groups

TABLE I. INVENTORY OF THE GOALS AND THE PARAMETERS USED TO OBTAIN EACH GOAL

Goal	Parameter
Minimise interference	Transmit power, RB assignment, Beam forming parameters, CQI thresholds for MIMO scheme switching
Maximise/optimise coverage	Transmit power, Antenna parameters
Balance load	Transmit power, Antenna parameters, HO parameters, Cell reselection parameters, Tracking area parameters
Minimise energy consumption	Transmit power, Antenna parameters, Number of used Tx antennas
Maximise capacity	Transmit power, Admission control threshold, Congestion detection and resolution parameters, Scheduler parameters, Link level retransmission scheme parameters, Tracking area parameters, CQI thresholds for MIMO scheme switching
Minimise error rate	Channel power control parameters
Maximise access probability	RACH configuration
Maximise HO performance	HO parameters

Applying the concept of functional parameter groups on Table I reveals that the majority of the parameters fall under the same functional parameter group, as shown in Table II. As mentioned above, if a parameter contributes to several goals then all these goals and their corresponding contributors (parameters) are in the same functional parameter group. For example it can be seen in Table I that transmit power and antenna parameters appear in several goals, resulting in a parameter group comprising the majority of the parameters.

TABLE II. THE RESULING FUNCTIONAL PARAMETER GROUPS ACCORDING TO THE DEFINITION GIVEN IN FIG. 1

Group	Goals	Parameter
A	Minimise interference, Balance load, Minimise energy consumption, Maximise cell capacity, Maximise/optimise network coverage, Maximise HO performance	Transmit Power, Antenna parameters, RB assignment, HO parameters, Admission control threshold, Congestion detection and resolution parameters, Scheduler parameters, Link level retransmission scheme parameters, Cell reselection parameters, Number of used Tx antennas, Beam forming parameters, CQI thresholds for MIMO scheme switching, Tracking area parameters
B	Minimise error rate	Channel power control parameters
C	Maximise access probability	RACH configuration

Due to the strong coupling between the parameters and the goals, there will most likely be the need for a mechanism that coordinates the output of different self-organisation functionalities and governs the access to the parameters. The coordination mechanism will most likely be rather complex due to the intricate relationships between parameters and goals. The multi-faceted complexity of such a coordinator is further described in Section V.

IV. DEPENDENCY AND INTERACTION BETWEEN SELF-ORGANISATION FUNCTIONALITIES

In this section, the dependencies and interactions of use cases and their corresponding self-organisation functionalities are determined. The goal is to discover the functionalities that are strongly coupled and hence need to be coordinated. The analysis of the interactions is based on triggers, which represent situations where the network performance decreases and hence could benefit from the execution of a self-organisation functionality. The following triggers are proposed in this paper: low/high blocking, low/high dropping, low/high quality of service, low/high/imbalanced traffic load, low/high cell capacity, new site, coverage hole, and cell outage.

In many cases the network performance can be increased by aspiring towards more than one goal, e.g., blocking can be decreased by balancing the load or maximising the capacity. As shown in Table I the different goals are affected by several parameters. These parameters are changed by the self-organisation functionalities of different use cases. Hence, the triggers will initiate several self-organisation functionalities that will interact in order to improve the network performance. To gain information about the interaction of the self-organisation functionalities it is necessary to understand which self-organisation functionalities could improve the network performance for every trigger. First of all the different types of interaction between self-organisation functionalities will be described. The following interactions have been identified: *Trigger*, *Co-operate* and *Co-act*. The interactions of self-organisation functionalities will be illustrated using the trigger blocking.

A. Trigger

Consider the situation where a self-organisation functionality has just changed a parameter value to optimise a particular aspect of network performance. Due to the new network state it might be necessary that other self-organisation functionalities are activated to check if the parameter settings controlled by them are still reasonable. Hence these self-organisation functionalities should be started after the initial self-organisation ends, i.e., the first functionality triggers the other functionalities. Self-organisation functionalities that trigger each other are not coupled strongly and, hence, they do not need to be coordinated. Note that the term trigger is also used in the context of initial activation of self-organisation functionalities dependent on the network state.

B. Co-operate

If the network performance decreases the self-organisation functionality will be activated to counteract the performance degradation. Consider the case where several self-organisation functionalities are activated at the same time by the same system performance degradation. This will be termed co-operation of self-organisation functionalities. To coordinate the different self-organisation functionalities an intensive information exchange between them or a separate coordination entity is necessary. The self-organisation functionalities of co-operating use cases are strongly coupled and need to be coordinated.

C. Co-act

Different self-organisation functionalities that change the same radio parameters may be active in parallel. If these self-organisation functionalities are activated by different triggers they might try to achieve different goals by changing the same parameters. This can be derived from Table I where it is shown that some radio parameter settings affect the achievement of different goals. The associated self-organisation functionalities have no requirement to co-operate when increasing the system performance, but co-act on the same parameters. Due to different triggers, this interaction might lead to continuous parameter changes in the self-organisation functionality. When implementing these algorithms it is necessary to assure that co-acting self-organisation functionalities are coordinated and stable.

D. Example of interactions for the trigger "Blocking"

Blocking is triggered when mobiles cannot be granted access to the network. The interactions of self-organisation functionalities for the trigger *Blocking* are illustrated in Fig. 2. They have been derived from the descriptions of the use cases addressed in the SOCRATES project [18].

The trigger *Blocking* initiates several self-organisation functionalities, which are activated sequentially or in parallel. The sequential functionalities are triggered successively after the previous functionality ended (see section A). The parallel functionalities are triggered at the same time and co-operate on improving the network performance (see section B). The main purpose of Fig. 2 in this context is to show the intricate dependencies between the self-organisation functionalities of the use cases. To increase the readability of this paper we only focus on the interactions between the co-operating self-organisation functionalities that are strongly coupled. The overall coherence is more complex due to the self-organisation functionalities that are activated before and after the co-operating functionalities. A more detailed description of the interaction between the self-organisation functionalities can be found in [19].

Considering Fig. 2, we see that the self-organisation functionality of use cases 'Admission control', 'Load balancing', and 'Handover optimisation' are triggered at the same time to co-operate on the problem of a high blocking rate. The self-organisation functionality of the 'Admission control' use case adapts the admission control thresholds to avoid unnecessary blocking. The self-organisation functionality of the 'Load balancing' use case aims at distributing the load among the surrounding cells by changing the transmit power or HO thresholds. The HO parameter settings are changed by the self-organisation functionality of use case 'Handover optimisation' as well, which aims at avoiding ping-pong handovers and increasing the HO success rate. An intensive information exchange between these self-organisation functionalities or a separate entity will be necessary to coordinate the self-organisation functionalities due to the strong coupling between their parameter settings.

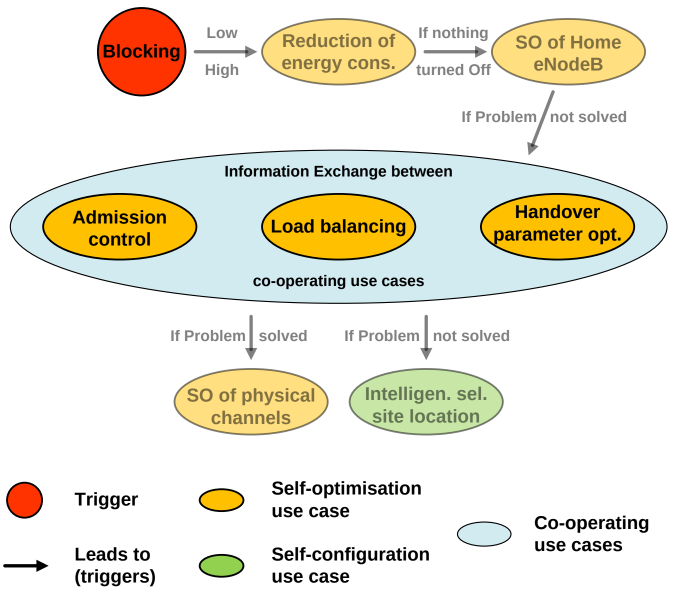

Figure 2. Interaction of use cases for the trigger *Blocking*

E. *Other Triggers and Interactions*

The interactions of self-organisation functionalities have been determined likewise for other types of triggers, more details can be found in [19]. The complexity of the dependencies between the self-organisation functionalities is similar for the other triggers. In addition to the co-operation of self-organisation functionalities there will be co-acting on the same parameter settings between functionalities activated by different triggers. As such, coordination between the self-organisation functionalities is required due to the complex interactions and dependencies between them.

V. COORDINATION PLANE

Dependencies between the different use cases may cause conflicts in the self-organisation, in the sense that two or more concurrent self-organisation functionalities may perform or request contradicting actions. It is proposed to handle this by a coordination mechanism in the so-called *coordination plane*. The *coordination plane* is part of the (logical) SON system architecture presented in Fig. 3. System measurements are collected in the *measurement plane*. The *control plane* compares the measurements against operator defined thresholds and decides on the activation of triggers. Based on these triggers one or more functionalities might be activated (see Section IV). The above mentioned *coordination plane* processes the parameter changes proposed by concurrent functionalities before parameter adjustments are actually carried out.

The diverse characteristics of the different self-organisation functionalities put complex requirements on the coordination mechanism. Functionalities can be expected to operate iteratively for some period of time. In each iteration, measurements are taken over an observation period, followed by a parameter adjustment. The iteration loop is terminated once a certain drop-out criterion is fulfilled, e.g., the target quality is reached, or no further improvements can be made. The time-scales on which functionalities operate differ drastically (minutes, hours, days, or even weeks). Moreover, there might be great differences in dimension of geographic area and number of network elements that are considered by functionalities. The coordination mechanism has to take these aspects into account in order to avoid any conflicting actions of concurrent functionalities.

Two types of conflicts may occur in a self-organising network. The first type is referred to as *parameter value conflict*, i.e., two or more functionalities are requesting different values on the same parameter. The coordination mechanism (asynchronously) receives parameter settings resulting from the individual self-organisation functionalities. If different settings are suggested for the same parameter by two or more self-organising functionalities, the coordination mechanism needs to derive a new setting for that parameter.

The second type of conflict, the *goal conflict*, is more complex. A goal conflict may occur if a metric optimised by one functionality is negatively affected by one or several other functionalities aiming at optimising other metrics. In order to work properly, possible conflicts need to be identified. While parameter value conflicts can easily be identified both in advance and during operation, it is harder to identify goal conflicts. Therefore, an extensive analysis of the self-organisation functionalities needs to be performed before implementing the coordination mechanism. For each functionality the possible effects on the goals of other functionalities have to be analysed and strategies for solving possible conflicts should be developed.

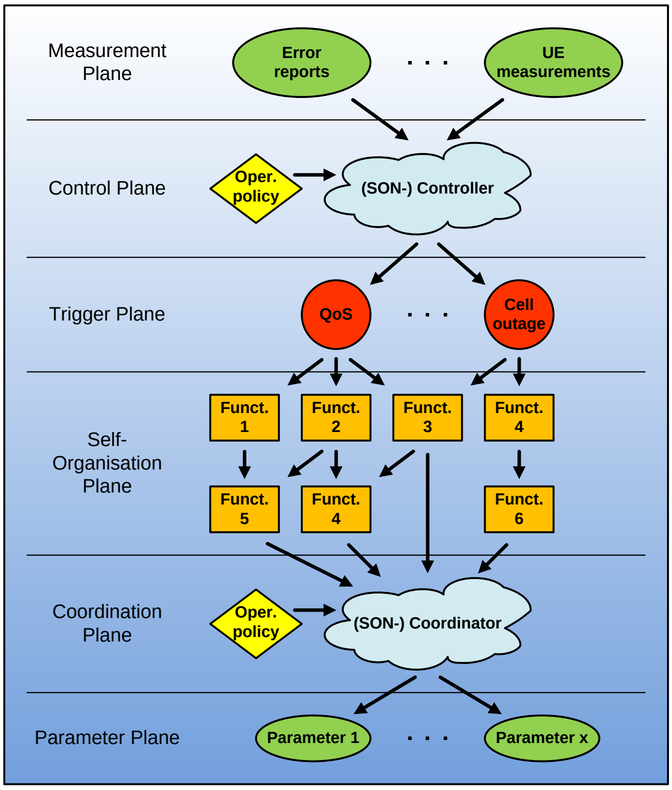

Figure 3. The overall SON system

Details on how the conflict resolution should be performed for the two conflict types are left for future work. One possible solution might be by prioritisation between the self-organising functionalities, between different parameter settings, or based on a combination of these. If priorities are applied, the coordination mechanism might, for example, restrict or prohibit parameter changes proposed by some lower priority functionality to the advantage of a higher priority functionality. Depending on the solution, the coordination mechanism might need to take the measurements from the measurement plane as input, or to send feedback to the self-organisation processes. Further, the operator should have the possibility to govern the conflict resolution by providing conflict resolution policies as input to the coordination mechanism.

The need of coordination between self-organising functionalities in the network will make the development of such functionalities extremely complex. Simulators used for testing the solutions require a very complex setting considering the possible interdependencies in a network. Not only the conflict resolution but also the decision on the location of the coordination functionality is a major challenge. At this stage the coordinator is considered as a logical unit that could be implemented as a central unit or in a distributed way, even as part of the individual self-organisation functionalities.

VI. SUMMARY AND RECOMMENDATIONS

This paper has presented the SOCRATES vision of self-organising wireless network and highlighted the main challenges when embedding multiple self-organising functionalities into the network. First, we defined the functional parameter groups, which define the coupling between the different self-organisation functionalities. Second, we characterised the interactions between the different self-organising functionalities and discovered possible conflicting relationships. Finally, a coordination plane was proposed that aims at conflict resolution between mutually coupled self-organisation functionalities. For the continuance of the SOCRATES project, the coupling between various radio parameters, interactions between different self-organisation functionalities, and the feasibility of the proposed coordination plane will be studied in more detail. This will be used to enable the development of suitable algorithms for an integrated SON solution.

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