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Use Cases, Requirements and Assessment Criteria for Future Self-Organising Radio Access Networks

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Use Cases, Requirements and Assessment Criteria for Future Self-Organising Radio Access Networks*

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Abstract. Self-organisation (self-optimisation, self-configuration, and self-healing) methods are a promising concept to automate wireless access network planning, deployment and optimisation. In this paper, first the mechanisms are identified for which self-organisation is anticipated to be effective and feasible. Then technical and non-technical requirements that need to be taken into account for the successful development of self-organisation functionalities are discussed. Furthermore, a set of metrics and appropriate reference cases (benchmarks) are presented, which allow to do on one hand a quantitative comparison of the different algorithms developed for a given use case, and on the other hand to evaluate the gains from self-organisation by comparing self-organisation solutions with the case of manual network operations.

1. Introduction

As recognised by the standardisation body 3GPP (3rd Generation Partnership Project) [1] and the operators' lobby NGMN (Next Generation Mobile Networks) [2], future wireless access networks, such as the 3GPP LTE (Long Term Evolution) radio access E-UTRAN (Evolved UTRAN), will exhibit a significant degree of self-organisation. The principal objective of introducing SON (Self-Organising Network) functionalities in wireless access networks is to reduce the costs associated with network operations, while enhancing network performance. By diminishing the manual effort in network operational tasks, significant OPEX (Operational Expenditure) reductions are expected, while because of the better adaptation to changing network characteristics and failures, it is anticipated that SON features will enhance the global network capacity, coverage and service quality experienced by the users.

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For the fruitful development of SON methods for future wireless access networks, it is essential to first identify the mechanisms for which self-organisation is anticipated to be effective. Moreover, it is necessary to have a clear view on the (non-)technical requirements put on SON solutions. Once the use cases and requirements are determined, criteria should be defined that can be used to evaluate the feasibility and performance of the developed SON methods.

The goal of this paper is to present use cases (Section 2), requirements (Section 3) and assessment criteria (Section 4) for the development of future self-organising radio access networks. All material presented in this paper is developed within the context of the European FP7 research project SOCRATES (Self-Optimisation and self-ConfiguRATion in wirelEss networkS) [3,4]. While 3GPP and NGMN provide the definitions of use cases and interfaces for SON, SOCRATES aims at providing dedicated solutions, i.e., methods and algorithms, as a step towards the implementation of SON functionality into future wireless access networks, where 3GPP E-UTRAN has been selected as the radio access technology of focus. However, before starting on detailed technical work and the development of algorithms, it is necessary to clearly identify use cases, requirements and assessment criteria, which is the topic of the current paper.

2. Use Cases for Self-Organising Access Networks

Use cases are an established means of describing what a solution to a particular problem shall achieve. Within the SOCRATES project, over twenty-five use cases that focus on self-organisation in 3GPP E-UTRAN have been identified. These include for example the self-configuration use cases 'intelligently selecting site locations' and 'automatic generation of default parameters for network element insertion', the self-optimisation use cases 'packet scheduling optimisation', 'interference coordination', 'admission control parameter optimisation' and 'load balancing', and the self-healing use case 'cell outage management'. Three of the use cases will be considered in more detail in this section. See [5] for a more extensive description of these and the other use cases.

The classification of the use cases in the three categories, i.e., self-configuration, self-optimisation and self-healing, is in line with the framework SOCRATES envisions regarding the use of self-organisation methods in future radio networks, as illustrated in Figure 1 [3,4]. Newly added NEs (Network Elements) like e.g., base stations (eNodeBs), *self-configure* in a 'plug-and-play' fashion, while existing NEs continuously *self-optimise* their operational algorithms and parameters in response to changes in network, traffic and environmental conditions. The adaptations are performed in order to provide the targeted service availability and quality as efficiently as possible. In the event of a cell or site failure, *self-healing* methods are triggered to alleviate the performance effects due to the resulting coverage/capacity gap by appropriately adjusting radio parameters in surrounding sites. In general, human involvement shall only be triggered when absolutely necessary, e.g., when deployments of new sites or manual repairs are needed.

For some of the identified use cases, such as interference coordination, 3GPP is already considering the implications on standardisation. However, few final decisions have been made and no flexible mechanisms allowing for vendor-specific solutions have yet been standardised. Other use cases such as for example admission control parameter optimisation or packet scheduling parameter optimisation, have received little attention so far. Note however that 3GPP does not intend to standardise full technical solutions for the use cases. The focus of 3GPP is on technical enablers such as measurement capabilities, harmonised notions of quality indicators, interfaces and flexible protocols.

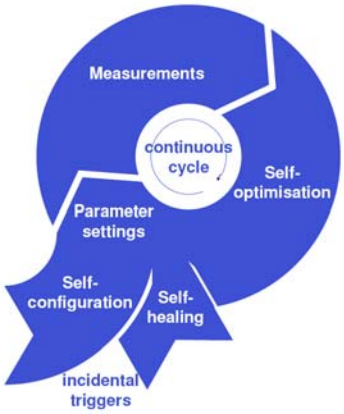

Figure 1. Self-organisation in future wireless networks.

2.1 Self-Configuration Use Case: Intelligently Selecting Site Locations

The intelligently selecting site locations use case is a mixture of the classical performance management and network planning tasks. The objective of the use case is to automatically calculate in case of bad coverage or bandwidth shortage, whether there is a need for a new base station, and what the ideal location or topology specific location for that new base station is. It is expected that by preparing the new network configuration, this use case accelerates the subsequent configuration update, and that it also reduces the manual effort for network optimisation and coverage. Although this use case does not completely match the self-configuration definition given before, we classify it as a self-configuration use case. If a new base station needs to be added, preparations for the (re)configuration of parameters like e.g., neighbour lists, will be made.

The trigger for the automated selection of new site locations requires a continuous or periodical analysis of appropriate performance measurement data. The attainment of pre-defined or self-learned threshold values then triggers the calculation of a solution. For example, an operator could define a dedicated number of call drops, call blockings, or a too low throughput, per area unit, due to bad coverage or bandwidth shortage, as a threshold.

The performance measurements that serve as input for this use case are the measurements as they are already used today for long-term network performance management. However, to automate the selection of a site location the measurement periods may have to be shortened, to allow a fine grained analysis of coverage or bandwidth problems, especially during busy hours. Depending on the required real-time capabilities of the use case, some real-time UE (User Equipment) counters or network element measurements (in case of multi-vendor solutions) may have to be standardised.

2.2 Self-Optimisation Use Case: Packet Scheduling Parameter Optimisation

As the evolving cellular networking technologies are more and more characterised by pure shared channel operation, in response to the efficiency-driven 'all IP' trend, the packet scheduler is becoming the chief *radio resource management* mechanism for managing the trade-offs between resource efficiency and service quality. The packet scheduler coordinates the access to shared channel resources in the time and/or frequency domain according to a vendor-specific algorithm. Such an algorithm generally comprises elements of service differentiation and channel adaptivity and is characterised by different parameters, affecting the type and degree of service differentiation (e.g., strict prioritisation or weighted fair queuing) and channel adaptivity (applying e.g., a proportional fairness principle).

Considering the key role of the packet scheduling mechanism it is of vital importance that its parameters are appropriately tuned to the actual system, traffic and propagation conditions. We anticipate that the optimal scheduling parameters primarily depend on the service mix, the spatial user distribution and traffic characteristics. It is the objective of this use case to *self-optimise* the scheduling parameters in order to achieve the individual service quality requirements of all on-going calls most efficiently and in accordance with the desired fairness. These parameter adjustments are made in response to noted changes in system, traffic and propagation conditions on one hand, and observations regarding potentially undesirable service quality and resource efficiency levels on the other hand. Based on continuous monitoring of these aspects, the self-optimisation algorithm associated with the packet scheduling scheme may be triggered e.g., when the traffic mix has changed significantly, when a significant QoS imbalance is observed, or when the observed resource efficiency falls below what can be expected. In all such events, which may typically occur on a time scale of minutes or hours, the self-optimisation algorithm retunes the scheduling parameters to fit the new circumstances.

2.3 Self-Healing Use Case: Cell Outage Management

A cell is in outage when the UEs, in the planned coverage area of the cell, cannot establish and/or maintain all or a limited set of the RBs (Radio Bearers) via that particular cell due to hard- and/or software failures at the serving eNodeB.

This umbrella use case comprises cell outage prediction, detection and compensation. The *cell outage prediction* function gives an early warning, assists to speed up the actual cell outage detection and also starts preparatory actions in the cell outage compensation function. The *cell outage detection* function notices that at the current time an outage has occurred and triggers the cell outage compensation function to take appropriate actions, while also notifying the maintenance department. The goal of *cell outage compensation* is to minimise the network performance degradation when a cell is in outage. This is done by automatic adjustment of network parameters (see Figure 2) in order to meet the operator's deployment requirements regarding coverage and key performance indicators, e.g., number of supported users, capacity and data rates, to the largest possible extent. Cell outage compensation algorithms may for example modify the antenna tilt and azimuth, or the cell transmit power, in order to increase the coverage of the neighbours to the cell in outage.

Automated reconfiguration as a response to cell outage aims at completely, or to the largest extent possible, alleviating and compensating outage in the area previously served by the missing or poorly performing cell. There may be an upper limit for the degree of compensation that is actually possible. For example, assume that a hardware failure occurs at a cell resulting in a total shutdown of the eNodeB. In this case, only parts of the original cell may be covered by neighbouring cells as a result of insufficient UE and/or cell transmit power. Hence, the algorithm cannot compensate for the cell outage entirely.

Altering the radio parameters of the neighbouring cells means that some of the UEs served by neighbouring cells may be affected, e.g., the capacity for those UEs may decrease. This should be taken into account and an appropriate balance, e.g., based on the operator policy, should be achieved. For example, the operator may define a region in the vicinity of the cell in outage where the number of supported UEs should be maximised.

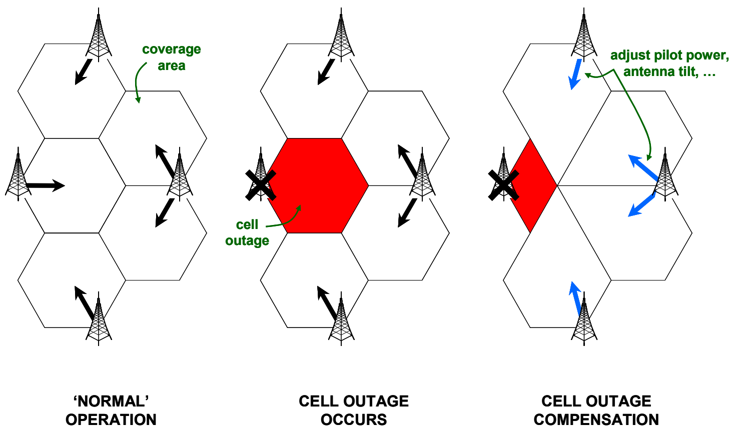

Figure 2. Illustration of cell outage compensation. The coverage loss due to the cell outage is partially compensated for by adjusting e.g., pilot power and antenna tilt of neighbouring cells.

3. Requirements for self-organising access networks

Several types of requirements must be considered in the successful development of SON functionalities, including technical and business requirements. The details of the use case-specific requirements can be found in [6].

3.1 Technical Requirements

In this section, some general categories of technical requirements, which will guide the development of new SON algorithms and functionalities, are considered.

- **Performance and complexity requirements:** For all SON use cases, a key requirement is that an appropriate balance should exist between the performance gains established by adding SON functionality and the implementation complexity, which is a clear trade-off. Implementation complexity can thereby be measured by means of e.g., the extra signalling over the radio interface and transport network, required measurements, computational effort, memory requirements and storage requirements.
- **Stability requirements:** The parameters altered by SON algorithms and the resulting impact on coverage, capacity, QoS etc. should converge and reach a stationary and optimised solution. Other parameters should not diverge nor oscillate significantly.
- **Robustness requirements:** Missing, wrong or corrupted measurements or measurement reports should be identified by the SON algorithms and measures to deal with these should be implemented, such that the algorithms still provide satisfying output.
- **Timing requirements:** Each use case has individual requirements, ranging from milliseconds to hours or days, so no general requirements can be given. For the packet scheduling parameter optimisation algorithm for example, the algorithm needs to be triggered at a time scale ranging from minutes to hours, since significant changes in the traffic pattern, mobility pattern, service mix or propagation and interference characteristics also occur in the order of minutes to hours. Once the algorithm is triggered, it should converge in a time in the order of minutes or less. The cell outage compensation algorithm for example should determine new parameter settings sufficiently fast, meaning in the order of seconds or at most minutes, after being triggered by the cell outage detection algorithm.
- **Interaction requirements:** Especially for the self-optimisation use cases, it is imperative to establish coordination between all the algorithms that modify the same parameters or influence the same performance or coverage targets. A conflict is said to arise in case the induced parameter changes or intended performance or coverage changes are of opposite nature or different magnitude. Adequate interaction therefore requires clear specification of conflict handling rules. To give an example, the cell outage compensation algorithm may adjust pilot powers to direct traffic to non-outage cells, upon which the load balancing algorithm may respond to the induced traffic load imbalances with undesirable countermeasures.
- **Architectural and scalability requirements:** SON algorithms can be implemented in a central or a distributed way. For centralised implementations, centralised monitoring, data storage and data analysis capabilities are required. If the algorithms are implemented in a distributed way, appropriate computing power, memory and storage capacity at the NEs are required.

- **Required inputs (performance counters and measurements):** Each use case has its individual input requirements. For example, for the intelligently selecting site locations use case, these include the current radio configuration parameters, performance information and measurements of the considered NEs and cells, topology and geographical data, network usage patterns and measurements from the mobiles.

3.2 Business Requirements

Since solutions that are good from a purely technical point of view may not necessarily meet business requirements, it is also important to consider these requirements. The business requirements are divided into cost efficiency requirements and LTE deployment requirements.

- **Cost efficiency requirements:** Cost efficiency is an important factor in determining the success of a network technology. If the cost of rolling out a network is too high, it becomes difficult to provide a profitable consumer service on the network. This leads to the following requirements:
  - *SON solutions should reduce OPEX* by reducing the significant effort that is traditionally required to roll out and operate a network.
  - *SON solutions should reduce CAPEX (Capital Expenditure)* by more efficiently using radio resources and hence demanding fewer base stations. However, adding SON functionality will potentially increase the cost of equipment, including terminals, base stations and operations and maintenance systems, due to the need for additional hard- and/or software. Therefore, SON impact on the cost of the entire mobile network should be considered.

  It is expected that OPEX reductions will be more significant than CAPEX reductions.
- **LTE deployment:** When considering SON, it is also necessary to consider the deployment of LTE networks, yielding the following SON requirements:
  - *The roll-out of LTE networks should be sped up:* when a network is first rolled out, there are usually many problems to solve before satisfactory performance is achieved. SON solutions should reduce these problems, and reduce the time before cells go live.
  - *SON solutions should simplify processes:* self-organisation functionalities should be developed and embedded in the network such that operational tasks are simplified. Also the setup and operation of SON solutions should be straightforward, not requiring significant manual effort.
  - *New services should easily be deployed:* new services may have new QoS requirements, which the SON solutions should be able to support with minimum required configuration.
  - *The end user should benefit:* the users should experience high GoS/QoS.

4. Assessment criteria for self-organising access networks

An adequate assessment of the benefits from developed self-organisation methods requires a set of well-defined metrics and appropriate reference cases (benchmarks). In the present context of self-organisation in wireless access networks, the most important metrics assess network capacity, coverage, service quality and OPEX/CAPEX. With regard to the reference cases, on one hand different self-organisation algorithms may be compared with one another, while on the other hand an appropriate 'manual reference case' needs to be defined to allow evaluation of the gains from self-organisation with respect to contemporary and manually operated networks.

4.1 Metrics

In this section, we describe the key performance metrics that are relevant in the assessment of self-organisation methods, organised in different categories: performance metrics, coverage metrics, capacity metrics and OPEX/CAPEX.

- **Performance metrics:** These metrics express the service level experience from the user perspective and include *grade of service*, e.g., call blocking ratio, call dropping ratio, and *quality of service* metrics, e.g., packet delay statistics, packet loss ratio, transfer time statistics, throughput statistics, mean opinion score, fairness.
- **Coverage metrics:** Different coverage metrics exist, e.g., the *service coverage*, i.e., the fraction of area where a given service can be supported with adequate service quality and the *data rate coverage*, i.e., the fraction of area where a user can experience at least some specified data rate.
- **Capacity metrics:** Cell (or network) capacity is not unambiguously defined and different sensible perspectives are applied in the literature:
    - *Maximum number of concurrent calls:* For a given scenario in terms of network layout, propagation environment, service mix, traffic characteristics and spatial traffic distribution, the cell capacity is given by the maximum number of concurrent (and persistent) calls in each cell that can be supported under a pre-specified quality of service requirement.
    - *Maximum supportable traffic load:* For a given scenario, now including the call level dynamics that are due to the random initiation and completion of calls, the cell capacity is given by the maximum aggregate call arrival rate in each cell that can be supported under pre-specified quality of service and grade of service requirements.
    - *Spectrum efficiency:* Having obtained the maximum number of concurrent calls (see above), the spectrum efficiency is equal to the corresponding aggregate net bit rate per cell, divided by the system bandwidth.
- **CAPEX:** In general, CAPEX encompasses the investments needed in order to create future benefits, including e.g., radio and core network elements. The following should be considered when estimating CAPEX associated with a given self-organisation solution:

- A proposed approach to estimate CAPEX is to determine the number of network elements that is needed to cover a certain service area with pre-specified grade and quality of service requirements, and multiply this with the corresponding costs. Given a certain service demand per km^2, the required number of network elements can be determined by maximising the cell radii such that traffic demand per cell and cell capacity are sufficiently well balanced to meet the grade and quality of service requirements, following similar evaluation methods as proposed for the above-mentioned capacity definitions.
- An additional aspect to consider is that the introduction of self-organisation features themselves may lead to an increase in equipment cost (per unit). The additional CAPEX is hard to estimate, but depends on the nature and complexity of the self-organisation algorithm, the transmission bandwidth requirements that may be higher due to increased signaling overhead, and additional costs related to needed site equipment, e.g., electrical antenna tilt and additional circuitry for enabling power savings.

- **OPEX:** The costs associated with the network operations and, in particular, the reduction of these costs due to the introduction of self-organisation functionalities, are rather difficult to assess. Noting that actual OPEX reductions depend on the degree of self-organisation that is deployed, in an extreme implementation, all OPEX related to manual adjustment of a given parameter set (associated with a use case) is removed. In order to develop an approach to assess the OPEX level, we distinguish between three main phases in effectuating parameter adjustments, i.e., *gathering input data*, e.g., via performance counters, drive tests or planning tools; *determining new parameter settings*, using (some combination of) manual adjustments and/or computer-aided adjustments using planning tools or advanced simulation models; and *applying new parameter settings*, which may be done remotely or requires a site visit.
  Depending on the applied methods, a use case-based estimation of the human effort in man hours involved in the three distinct phases can be made by the operator[†]. Multiplied by the effective cost per expert hour, the number of times per year such a parameter adjustment is needed (see Section 4.2) and a multiplication factor that reflects the number of cells (or cell classes) for which separate parameter adjustments need to be made, yields the OPEX per year for the considered use case.

  In case self-organisation functionalities are applied, their specific impact on the above-mentioned distinct components that contribute to OPEX should be assessed, based on the properties of the developed solutions. Note that for some components the required human effort is significantly reduced, while for others it remains unchanged.

[†] Note that this depends on the operator policy: a cost-driven operator is likely to spend less effort on network planning and optimisation than a quality-driven operator.

4.2 Benchmarking

A key objective in the development of methods for self-organisation is to do a quantitative comparison of different methods developed for a given use case, and to compare their achieved performance, capacity and cost to a case with manual network operation. Below we describe an approach for such benchmarking. The approach is primarily outlined from the perspective of a self-optimisation use case, although it is readily converted to cover self-configuration and self-healing use cases as well.

Starting point is a specific scenario in terms of e.g., the propagation environment, service mix, traffic characteristics and spatial traffic distribution. For such a scenario, the achievements of the different self-optimisation algorithms can be expressed in terms of the metrics described in Section 4.1, including an estimation of the optimisation effort that is based on the observed number of automatic parameter adjustments per time unit. Note that if the optimisations were done manually, this would indicate the OPEX level. Figure 3 visualises example fluctuations in the traffic, mobility and propagation characteristics, and the period of the algorithm-specific induced radio parameter adjustments.

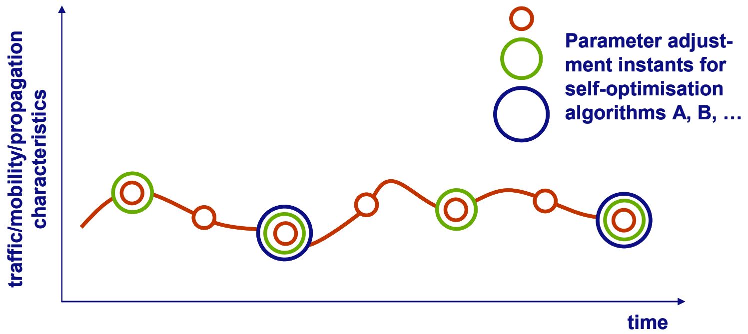

Figure 3. Algorithm-specific timing of radio parameter adjustments.

Example values of the metrics obtained at the end of simulation studies are shown in Figure 4. Observe that e.g., self-optimisation algorithm SO_A achieves the highest performance, which can be exploited to achieve the lowest CAPEX, but in order to achieve this, a large optimisation effort is required. In contrast, algorithm SO_D is significantly less complex but consequently achieves worse performance and CAPEX.

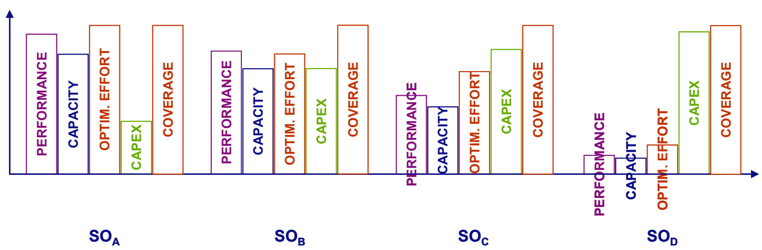

Figure 4. Example values of obtained metrics.

In general, it is hard to compare the different self-optimisation schemes given the conflicting performance objectives. One possible approach to enforce a strict overall ranking is to weigh/combine the different measures into some utility function and rank the algorithms based on the obtained utility values.

Whereas the above discussion outlines an approach to compare different self-optimisation algorithms, a more difficult challenge is to compare a self-optimisation algorithm with a case of manual optimisation. In an extreme case, one could assume that a 'manual operator' freezes permanent settings of his radio parameters, which should then be chosen such that the overall performance is optimised, considering the given scenario with varying traffic, mobility, propagation etc. characteristics. In practice, however, a network operator will upon observed need or sensibility adjust the radio parameters. Depending on the operator's policy this may happen more or less frequently: a quality-oriented operator is likely to do more frequent adjustments than a cost-oriented operator. In order to model this in a reasonable way, we propose to define 'manual optimisation algorithms' MO_A through MO_D (continuing the above example) such that they manually adjust radio parameters at the same time and to the same values as would the corresponding self-optimisation algorithms with the same label. An example comparison of SO_A with MO_D is visualised in Figure 5, concentrating on CAPEX and OPEX-related measures.

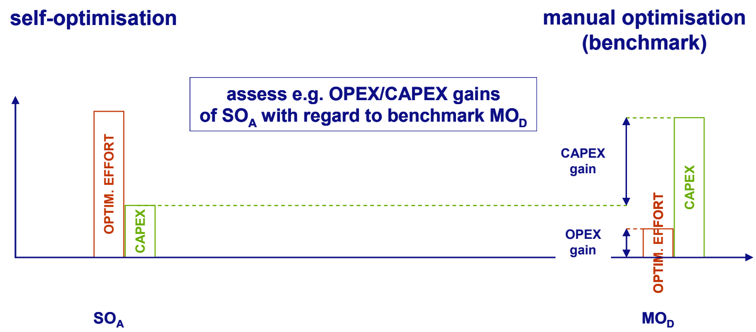

Figure 5. Comparison of SO_A with regard to benchmark MO_D.

Assuming that self-optimisation reduces OPEX to zero (which may be too extreme, but is fine for illustrative purposes), the OPEX and CAPEX gains are indicated in Figure 5. Note that the OPEX gain is determined by the optimisation effort that applies in the manual case. Continuing this approach for different combinations of SO_X and MO_Y we could generate tables such as Table 1, where the '+', '-' and '0's are just qualitative indicators; actual numerical values should be determined via simulation studies. Observe that introducing self-optimisation in the network of a quality-oriented operator is likely to establish the highest OPEX gains, but the lowest CAPEX gains.

Table 1. Comparing self-organisation algorithms with manual algorithms.

		CAPEX GAINS				OPEX GAINS			
		SO_A	SO_B	SO_C	SO_D	SO_A	SO_B	SO_C	SO_D
quality oriented operator	MO_A	0	-	--	---	++++			
	MO_B	+	0	-	--	+++			
	MO_C	++	+	0	-	++			
cost oriented operator	MO_D	+++	++	+	0	+			

5. Concluding remarks and future work

In this paper we have identified use cases, requirements and assessment criteria for future self-organising radio access networks. Within the SOCRATES project, these will form the basis of a framework for the development of self-organisation methods and algorithms, which describes among other things the relation and dependencies between the different components of SON. As future work, SON algorithms for the use cases will be developed, while the identified requirements will be taken into account. The proposed assessment criteria will then be used to evaluate the developed algorithms and solutions. As at this early stage of LTE development, a live test of developed SON algorithms in the field is not yet possible, the actual comparison and assessment of the different developed SON solutions will be done by performing simulation studies. The future work also includes the integration of the developed SON solutions, to ensure consistent behaviour when the developed algorithms are operated simultaneously.

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