Assessment criteria for self-organising networks

Abstract:
The SOCRATES (Self-Optimisation and self-ConfiguRATion in wirEless networkS) project aims at the development of self-organisation methods for LTE radio networks. Self-organisation comprises self-optimisation, self-configuration and self-healing. In this document criteria and methodologies to assess the solutions for self-organisation are described, together with the reference scenarios that will be used for assessing the developed solutions.

Keyword list:
Self-organisation, self-configuration, self-optimisation, self-healing, assessment criteria, metrics, benchmarking, reference scenarios, simulation models, drive tests
Executive Summary

The SOCRATES (Self-Optimisation and self-ConfiguRATion in wirEless networkS) project aims at the development of self-organisation methods for LTE radio networks. Self-organisation, comprising self-configuration, self-optimisation and self-healing, is expected to result in a reduction of the operational expenditure (OPEX) and in an increase of the network performance.

One of the project objectives is to do a mutual comparison of different self-organisation methods developed for a given use case, and moreover compare their achieved performance (GoS/QoS), capacity, cost, and revenue to the case with manual network operation. Therefore, in the first part of this document several metrics that can serve as assessment criteria are defined and methodologies to estimate CAPEX and OPEX are proposed. In addition, an approach that describes the procedure for benchmarking of self-organising network (SON) algorithms is provided. To examine the effectiveness of the defined metrics, their applicability is considered for three example self-organisation use cases.

The work in the present deliverable constitutes important input for the framework for the development of self-organisation methods to be established in WP2 (Use cases and framework) in the first phase of the project. The actual comparison and assessment of the different developed self-organisation solutions will be done by performing simulation studies in WP3 (Self-optimisation) and WP4 (Self-configuration and self-healing) in the next phase of the project. To make fair and correct comparisons possible, it will be needed that all simulations are performed using the same reference scenarios. The reference scenarios are defined in the second part of the present document. They include different mobility, traffic and propagation models that will be used in WP3 and WP4. This is needed in order to ensure the comparability of the simulation results that will be obtained. Furthermore, also the network topologies that will be considered in our future simulation studies are described in this document. The parameters for the ‘idealised’ hexagonal network topologies and the measurement data that will be available for the realistic network topologies are included. Finally, the drive tests that will be done in the real-world scenarios are described.
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<td>2G</td>
<td>Second Generation</td>
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<td>3G</td>
<td>Third Generation</td>
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<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<tr>
<td>BHCA</td>
<td>Busy Hour Call Attempts</td>
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<td>BS</td>
<td>Base Station</td>
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<td>BSIC</td>
<td>Base Station Identity Code</td>
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<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
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<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
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<tr>
<td>CDF</td>
<td>Cumulative Distribution Function</td>
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<tr>
<td>CIR</td>
<td>Carrier to Interference Ratio</td>
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<tr>
<td>eNB</td>
<td>E-UTRAN NodeB</td>
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<tr>
<td>E-UTRAN</td>
<td>Evolved Universal Terrestrial Radio Access Network</td>
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<tr>
<td>FLR</td>
<td>Frame Loss Ratio</td>
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<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
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<tr>
<td>GK</td>
<td>Gauß Krüger</td>
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<tr>
<td>GoS</td>
<td>Grade of Service</td>
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<td>GPRS</td>
<td>General Packet Radio Service</td>
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<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<tr>
<td>HSDPA</td>
<td>High-Speed Downlink Packet Access</td>
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<td>HSPA</td>
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<tr>
<td>HTTP</td>
<td>Hypertext Transfer Protocol</td>
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<tr>
<td>ID</td>
<td>Identity</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>LAC</td>
<td>Link Access Control</td>
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<td>LOS</td>
<td>Line of Sight</td>
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<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>MHA</td>
<td>Mast Head Amplifier</td>
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<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
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<tr>
<td>MME</td>
<td>Mobility Management Entity</td>
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<td>MOC</td>
<td>Mobile Originated Call</td>
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<tr>
<td>MOS</td>
<td>Mean Opinion Score</td>
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<td>MS</td>
<td>Mobile Station</td>
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<td>MSC</td>
<td>Mobile Switching Centre</td>
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<tr>
<td>MTC</td>
<td>Mobile Terminated Call</td>
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<tr>
<td>NLOS</td>
<td>Non Line of Sight</td>
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<tr>
<td>OPEX</td>
<td>Operating Expenditure</td>
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<tr>
<td>OSS</td>
<td>Operations Support System</td>
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<tr>
<td>PDCP</td>
<td>Packet Data Convergence Protocol</td>
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<tr>
<td>PDF</td>
<td>Probability Distribution Function</td>
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<td>PLR</td>
<td>Packet Loss Ratio</td>
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<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
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<td>Quality of Service</td>
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<td>RAC</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<tr>
<td>Rx</td>
<td>Receive</td>
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<td>SCM</td>
<td>Spatial Channel Model</td>
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<tr>
<td>SDU</td>
<td>Service Data Unit</td>
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<tr>
<td>S-GW</td>
<td>Serving Gateway</td>
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<tr>
<td>SID</td>
<td>Speech Codec Silence Insertion Description</td>
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<tr>
<td>SINR</td>
<td>Signal to Interference and Noise Ratio</td>
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<tr>
<td>SON</td>
<td>Self Organising Network</td>
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<tr>
<td>TMA</td>
<td>Tower Mount Amplifier</td>
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<tr>
<td>TRX</td>
<td>Transceiver</td>
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<tr>
<td>Tx</td>
<td>Transmit</td>
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<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
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<tr>
<td>UE</td>
<td>User Equipment</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<tr>
<td>URA</td>
<td>User Registration Area</td>
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<tr>
<td>VAF</td>
<td>Voice Activity Factor</td>
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<td>VoIP</td>
<td>Voice over IP</td>
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<td>WP</td>
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1 Introduction

It is expected that the key gains from employing self-organisation in wireless access networks, comprising self-configuration, self-optimisation and self-healing, will be in the form of OPEX reductions and enhanced performance. In the work packages 3 and 4 of the SOCRATES project, algorithms will be developed for several of the self-organisation use cases that were identified in the SOCRATES deliverable D2.1 ‘Use Cases for Self-Organising Networks’ [1]. This deliverable focuses on the criteria that will be applied when assessing the gains of the self-organisation solutions, and on the reference scenarios that will be used for simulating these solutions.

This document is divided into two parts:

- **Assessment criteria**, discussing criteria and methodologies to assess the gains that can be achieved using self-organising networks, and to evaluate and compare the future self-organisation algorithms that will be developed in the project (Chapter 2).

- **Reference scenarios**, discussing reference scenarios based on hexagonal and real-world network topologies, including the models for mobility, traffic, propagation, etc., that will be used in the simulations of the future self-organisation algorithms (Chapter 3).

Concluding remarks are made in Chapter 4.

1.1 Assessment criteria

The assessment criteria and methodologies defined in this document should serve two purposes, i.e., they should allow the assessment of the gains that can be achieved using self-organisation networks, and they should make an evaluation possible of the algorithms that will be developed, including answering the question ‘which algorithm is best’ in case more than one algorithm is developed for the same use case.

First several performance (GoS/QoS) (Section 2.1.1), coverage (Section 2.1.2) and capacity (Section 2.1.3) metrics are presented that will aid in the evaluation and comparison of the self-organisation algorithms. Besides that, these metrics may also be used as triggers for the self-organisation algorithms, because changing performance (GoS/QoS), coverage or capacity values could identify new changes in network characteristics, coverage problems, unsuitable parameter settings, etc.

Then models for determining revenue (Section 2.1.4), CAPEX (Section 2.1.5) and OPEX (Section 2.1.6) are proposed. The reason why besides models for OPEX and CAPEX also a model for determining revenue is needed, is to assess the monetary advantage of ‘otherwise missed value’ when applying self-healing.

Finally also some other metrics like stability, convergence time, etc., are considered (Section 2.1.7). These metrics were also considered as technical requirements in the SOCRATES deliverable D2.2 ‘Requirements for Self-Organising Networks’ [2]. They are subordinate to the performance metrics in the sense that e.g., slow algorithm convergence will have a negative impact on the GoS/QoS, but an important part of their assessment will be whether the technical requirements are met by the developed algorithms.

It is expected that self-organisation features will enhance the global network capacity, performance and service quality experienced by the user, because of the better adaptation to changing network characteristics and failures. Also for OPEX the introduction of SON functionality is expected to result in OPEX reductions, because of reductions in manual effort in network planning, monitoring and optimisation, and in performing drive tests. For CAPEX, the introduction of self-organisation may result in a reduction because of delayed investments, but it may however also result in an increase of CAPEX, because of increasing equipment costs. This will depend on the self-organisation algorithm and on several factors associated with the algorithm. To make a comparison of the difference in performance (GoS/QoS), capacity, OPEX, CAPEX, etc. in scenarios with and without SON possible, the metrics should be estimated for network operations and optimisation processes with and without SON. An approach for such benchmarking is described in Section 2.2.

To examine the effectiveness of the defined metrics, in Section 2.3 their applicability is considered for three example use cases: the intelligently selecting site locations use case, which is a self-configuration use case, the packet scheduling parameter optimisation use case, which is a self-optimisation use case, and the cell outage compensation use case which belongs to the self-healing category of use cases.
1.2 Reference scenarios

The SOCRATES reference scenarios give a common platform for the simulation studies that will be done for the development and evaluation of the different algorithms for the self-configuration, self-optimisation and self-healing processes. It is the aim of the reference scenarios to make a fair and correct comparison of the algorithms developed by different partners possible. Therefore the different models and network topologies that will be considered in the SOCRATES simulation studies are defined in this document.

The description of the mobility models can be found in Section 3.1.1 This section contains simple mobility models like the random walk, random waypoint and Manhattan model, as well as a more detailed model, the MOMENTUM mobility model. The MOMENTUM mobility model can be used to generate movement based on realistic environment data.

The traffic models that will be considered in SOCRATES are described in Section 3.1.2. Various models like the full queue model, FTP traffic model, web browsing model, video streaming model, VoIP model and gaming model are defined in this section. In addition traffic mixes of the traffic types mentioned before are given at the end of the section.

Section 3.1.3 comprises the description of the propagation models including empiric propagation models, fading models, a multi-path model for MIMO and the description of the model used by the project partner Vodafone to calculate the coverage maps for the real-world scenarios.

Furthermore Section 3.2 includes the description of the different network topologies that will be considered in the simulation studies. The hexagonal network topologies will be used for standard simulations, whereas the realistic network topologies will be used for more detailed simulations.

Section 3.2.1 describes the hexagonal network topologies as they will be used in SOCRATES simulations.

Within the realistic reference scenarios, detailed information about the sites, the traffic and the environment is needed to allow appropriate development and evaluation of the algorithms. The two realistic scenarios described in Section 3.2.2 include all typical network configurations and different environmental areas applicable within the SOCRATES project. In Section 3.2.2.3 the desirable data for the reference scenarios is specified. The drive test measurements will be done by the Braunschweig Technical University (TUBS) in the areas of the reference scenarios. The measurement results will be available for all members of the SOCRATES project. Additional information about the drive tests can be found in the Section 3.2.2.4.

Different types of base transceiver stations (BTSs), namely Macro, Micro, Femto and Home eNodeBs, will be considered in SOCRATES. It has to be defined later in work packages 3 and 4 which models, network topologies and BTS types will be considered for the development and evaluation of the algorithms for every use case. It might be a good approach to initially start with simple models and simple network topologies and increase the accuracy of the models and network topology during the simulation studies.

It will most likely become necessary to update the reference scenarios i.e., the parameters of the models and network topologies, according to the future simulations in work packages 3 and 4. That is because later research might show that different parameter settings lead to more meaningful simulation results.
2 Assessment criteria

2.1 Metrics

In this section, several metrics are presented that will aid in the evaluation and comparison of the self-organisation algorithms that will be developed in the SOCRATES work packages 3 and 4. Several categories of metrics are considered, i.e., performance (GoS/QoS) metrics, coverage metrics, capacity metrics, revenue, CAPEX and OPEX, etc.

Besides for assessing the gain that can be achieved with self-organising networks and for evaluating self-organisation algorithms, the performance (GoS/QoS), coverage and capacity metrics could also be used for triggering actions of the self-organisation algorithms. Changing performance (GoS/QoS), coverage and capacity values could identify new changes in network characteristics, coverage problems, missing neighbour relations, UE failures, interference problems, unsuitable parameter settings, etc.

Note that throughout this document often the word *call* is used. As in [3], a call is defined as a sustained burst of user data. So we use ‘call’ not only in the context of a speech call or voice call, but it encompasses traffic flows originating from every possible type of service, like e.g., voice, video, data, gaming, etc.

2.1.1 Performance (GoS/QoS)

This section considers performance metrics that measure achieved GoS/QoS (Grade of Service / Quality of Service). GoS refers to performance associated with call blocking and call dropping, while QoS refers to performance associated with the quality of the calls in terms of delay, throughput, etc. All metrics considered in this section are related to what the user experiences. Capacity, which is also a performance metric but which is of more direct interest to the operator, is considered in Section 2.1.3.

2.1.1.1 Call blocking ratio

The call blocking ratio is the probability that a new call cannot gain access to the eNB / network. Call blocking occurs if the admission control algorithm does not allow the establishment of the new connection. The call blocking ratio is calculated as the ratio of the number of blocked calls (N_blocked) to the number of calls that attempt to access the network. The number of calls that attempt to access the network is the sum of the number of blocked calls and the number of accepted calls (N_accepted).

\[
\text{Call blocking ratio} = \frac{\text{N\_blocked}}{\text{N\_blocked} + \text{N\_accepted}}.
\]

2.1.1.2 Call dropping ratio

The call dropping ratio is the probability that an existing call is dropped before it was finished (for example, during handover, by congestion control, if the user moves out of coverage, etc.). It is calculated as the ratio of the number of dropped calls (N_dropped) to the number of calls that were accepted by the network (N_accepted):

\[
\text{Call dropping ratio} = \frac{\text{N\_dropped}}{\text{N\_accepted}}.
\]

2.1.1.3 Call success ratio

The call success ratio represents the number of successful calls (i.e., calls that are not blocked and not dropped) divided by the total number of call attempts (i.e., number of accepted + number of blocked calls).

\[
\text{Call success ratio} = \frac{(\text{N\_accepted} - \text{N\_dropped})}{(\text{N\_accepted} + \text{N\_blocked})}.
\]

Note that the call success ratio also equals

\[
\text{Call success ratio} = (1 - \text{call blocking ratio}) \times (1 - \text{call dropping ratio}).
\]

2.1.1.4 Packet delay

The packet delay is defined as the amount of time it takes to transfer a packet from eNB to UE, or vice versa, i.e., it is the transfer time of a single packet. Since the packet delay may vary from packet to packet, the cumulative distribution function (CDF) of the packet delay should be considered. From the CDF, average packet delay, packet delay percentiles, etc., can be calculated. Packets that are dropped will be excluded from the packet delay analysis. The impact of such dropped packets will be captured in the packet loss ratio (see Section 2.1.1.7).
The packet delay might be measured at different network layers. For example, the radio access packet delay is defined in terms of the transfer time (see Section 2.1.1.5) between a packet being available at the IP layer (Tx reference point) of the source (eNB or UE) and the availability of this packet at the IP layer (Rx reference point) of the destination (UE or eNB). When reporting on packet delay statistics, the exact layer and reference points between which the packet delay has been measured should be mentioned, since this might differ depending on the traffic model capabilities, simulator capabilities, etc.

2.1.1.5 Transfer time
Transfer time is the time needed to complete a data transmission. Transfer time is measured from when the first packet of a packet call is transmitted by the eNB until when the final packet of the packet call is received by the UE, or vice versa. Also for the transfer time metric, the CDF should be considered, as also the transfer time may vary depending on where the users are located in the cell. From the CDF, average transfer time, transfer time percentiles, etc. can be calculated. The transfer time can be measured at the different network layers.

2.1.1.6 Throughput
Throughput is the rate of successful data delivery. It is typically measured in bits per second or data packets per second, and calculated as the number of bits (or packets) that are successfully delivered in a certain time period, divided by the length of that time period.

The user throughput is defined as the ratio of the number of information bits (or packets) that the user successfully received, divided by the amount of time the user was actively involved in the data packet transfer. The packet call throughput of an application is defined as the number of bits (or packets) of the call divided by the call duration. The aggregate cell throughput is the sum of all user throughputs for the users associated with that cell.

For the throughput metric, the CDF should be considered, as the throughput may vary strongly depending on where in the cell the user is located. From the CDF, average throughput, throughput percentiles, etc., can be calculated. The measured throughput will be a function of the distance between the eNBs and the number of user per site. For throughput calculations, the fairness criterion (see Section 2.1.1.10) shall be fulfilled. Throughput metrics can be measured at the different network layers, and refer to the payload throughput without the overhead.

2.1.1.7 Packet loss ratio
Packet loss can be caused by a number of factors, e.g., signal degradation over the wireless network, buffer overflow in a network element, etc. Generally, packet loss is considered as the difference between the amount of packets sent by the source and the amount of packets received by the destination, i.e., the amount of packets dropped in the network, but in a wireless network packet loss might also occur due to a high bit error rate. Therefore, the number of lost packets is defined as:

\[ \text{Number of lost packets} = \text{number of packets sent by the source} - \text{number of packets successfully received by the destination} \]

The packet loss ratio (PLR) is then defined as

\[ \text{PLR} = \frac{\text{number of lost packets}}{\text{number of packets sent by the source}}. \]

Packet loss might again be measured at different network layers, but it is typically considered end-to-end for the higher layers (layer 3 and above).

2.1.1.8 Frame loss ratio
The frame loss ratio measures loss for the lower layers (L1 and L2). At L1, the 10 ms radio frames are considered, and at layer 2 a frame is a PDCP (packet data convergence protocol) SDU (service data unit). The frame loss ratio is the ratio of the number of lost frames to the number of attempted frame transmissions (Frames_offered). If the number of successfully delivered frames is referred to as Frames_delivered, then the number of lost frames (Frames_lost) is given by

\[ \text{Frames}_\text{lost} = \text{Frames}_\text{offered} - \text{Frames}_\text{delivered}. \]

And the formal definition of the frame loss ratio (FLR) is

\[ \text{FLR} = \frac{\text{Frames}_\text{lost}}{\text{Frames}_\text{offered}}. \]
2.1.1.9 Mean opinion score

Voice call quality testing has traditionally been subjective. The leading subjective measurement of voice quality is the mean opinion score (MOS). This measurement provides a numerical measure of the quality of the voice call at the destination end of the connection. It is expressed as a single number in the range 1 to 5, where 1 is lowest perceived quality, and 5 is the highest perceived quality.

Because subjective testing is difficult, objective measurements for voice call quality, like the E-model [4], have been standardised. The E-model assesses the quality of voice calls based on a wide range of impairments that influence the quality of a call, such as for example packet loss and delay. The output of the E-model is a single value, called R-value, which can be mapped onto a MOS value, as is shown in Table 1. The R-value is calculated as a sum of several components that in turn depend on several parameters, including network impairments like the mean one-way delay and the packet loss probability. A list of all E-model parameters, their interpretation, default values and nominal parameter ranges is available on http://www.itu.int/ITU-T/studygroups/com12/emodelv1/index.htm. This website also offers an online E-model calculation tool, which implements the E-model based on [4].

<table>
<thead>
<tr>
<th>R-value (lower limit)</th>
<th>MOS (lower limit)</th>
<th>User satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>4.34</td>
<td>Very satisfied</td>
</tr>
<tr>
<td>80</td>
<td>4.03</td>
<td>Satisfied</td>
</tr>
<tr>
<td>70</td>
<td>3.60</td>
<td>Some users dissatisfied</td>
</tr>
<tr>
<td>60</td>
<td>3.10</td>
<td>Many users dissatisfied</td>
</tr>
<tr>
<td>50</td>
<td>2.58</td>
<td>Nearly all users dissatisfied</td>
</tr>
</tbody>
</table>

Table 1: Relation between R-value, MOS and user satisfaction.

2.1.1.10 Fairness

In scenarios where multiple users share a common communication medium, there is an inherent competition in accessing the channel. Information theoretic results for such systems imply that in order to achieve high spectrum efficiency (see Section 2.1.3.3), the users with the stronger channel should have a higher portion of the resources. However, users expect to have the same experience regardless whether they are close to an eNB or at the cell edge. So metrics like e.g., cell throughput or transfer time, make only sense if a fairness criterion is fulfilled.

A first way to evaluate fairness is by determining the normalised cumulative distribution function (CDF) of the per user throughput. Let \( T(k) \) be the throughput for user \( k \), and let \( \text{Avg}(T) \) be the mean user throughput. The normalised throughput \( T^*(k) \) for user \( k \) is then given by \( T(k) / \text{Avg}(T) \). The fairness metric is then the normalised throughput bound, which is the region in the normalised throughput CDF plot where the throughput should at least be right of it. This region is defined by the line given by the points \((0.1,0.1)\), \((0.2,0.2)\) and \((0.5,0.5)\) in this plot (see Figure 1). The interpretation of this fairness criterion is that at least 90% of the users should have at least 10% of the average user throughput.

![Figure 1: Normalised throughput bound. A plot of the normalised throughput CDF should be right of this bound.](image-url)
Another fairness metric is *Jain’s fairness index* [5]. For a scenario with n users, this index is calculated by the following formula, where \( T(k) \) denotes again the throughput for user k:

\[
\text{Jain’s fairness index} = \frac{\left( \sum_{k=1}^{n} T(k) \right)^2}{n \sum_{k=1}^{n} (T(k))^2}.
\]

Jain’s fairness index reaches its maximum value of 1 when all users receive the same allocation.

### 2.1.1.11 Outage

The concept of user satisfaction is very important, but perceived quality is subjective. The outage metric attempts to associate an objective measure with user satisfaction. Objective user outage criterions are defined based on the application of interest. For example, in e.g., [3], [6], it is proposed that:

- A VoIP user is in outage if more that 2% of the VoIP packets are dropped, erased or not delivered successfully to the user within the delay bound of 50 ms.
- A user is defined in outage for the HTTP or FTP service if the average packet call throughput is less than 128 kbps.
- A gaming user is in outage if the average packet delay is larger than 60 ms.
- A user is defined in outage for the streaming video service if the 98th percentile of the video frame delay is larger than 5 seconds.

A system is said to be in outage when the number of users experiencing outage exceeds a certain percentage, for example 2% [6]. Notice that the numerical values mentioned above are just examples. It is to be expected that in LTE systems that are being designed as high data rate systems, users will expect for example a higher throughput for the HTTP or FTP service than 128 kbps.

### 2.1.1.12 Handover success ratio

The handover success ratio is the ratio of the number of successful handovers to the number of handover attempts. The number of handover attempts is the sum of the number of successful (\( N_{\text{HOsuccess}} \)) and the number of failed (\( N_{\text{HOfail}} \)) handovers.

\[
\text{Handover success ratio} = \frac{N_{\text{HOsuccess}}}{N_{\text{HOsuccess}} + N_{\text{HOfail}}}.
\]

Obviously,

\[
\text{Handover failure ratio} = 1 - \text{Handover success ratio}.
\]

### 2.1.2 Coverage

Several coverage metrics exist. The *SINR coverage* is defined as the percentage area of a cell where the average SINR experienced by a stationary user is larger than a certain threshold (target SINR), and the *data rate coverage* is the percentage area of a cell for which a user is able to transmit / receive successfully at a specified mean data rate. Note that these metrics are single-user metrics, i.e., these metrics are evaluated assuming that a single user is in a particular cell utilising all the resources in that cell. However, when multiple users are in the system, the system resources have to be shared and a user’s average data rate will be smaller than the single-user data rate. Therefore, also a multi-user metric like the *combined coverage and capacity index* is considered. This metric measures the number of users per cell that can simultaneously be supported in achieving a target information throughput \( R_{\text{min}} \) with a specified coverage reliability. Two methods to approximate this metric are explained in [7].

### 2.1.3 Capacity

The capacity of mobile access networks has no unique definition. In fact, different perspectives are applied in the literature. In this section, three distinct definitions are described.

#### 2.1.3.1 Maximum number of concurrent calls

One approach to determine the capacity of a mobile access network is to define a certain scenario, in terms of e.g., network layout, propagation environment, service mix, traffic characteristics, spatial traffic distribution and quality of service requirements, and then raise the uniform number of concurrent (and persistent) calls in each cell until the quality of service requirements can no longer be met. It is noted that
in spatially inhomogeneous scenarios, the thus obtained capacity may be dictated by a single densely populated cell, in which case conclusions should be carefully derived.

In order to illustrate this approach with an example, recently several VoIP-over-HSPA studies have been reported in the literature (see e.g., [8] and [9]). A typically followed approach is to simulate a multi-cellular HSPA network in a hexagonal layout where each cell serves \( n \) VoIP calls in parallel, modelled according to a some talkspurt-silence model. In separate simulation runs, different settings of \( n \) are considered and the achieved performance is measured in terms of e.g., a mean opinion score or the fraction of VoIP calls that experience a packet loss no greater than some preset target level. Given some minimum requirement on these metrics, the maximum value of \( n \) that satisfies this requirement is then reported as the VoIP capacity of the network (for the considered scenario, in terms of e.g., propagation environment, mobility characteristics, etc.).

2.1.3.2 Maximum supportable traffic load

The previous capacity measure ignored the call level dynamics that are due to the initiation and completion of calls. Since these dynamics generally have a significant impact on the service experience, it makes sense to also include this in the capacity definition. The approach is to define a certain scenario, in terms of e.g., network layout, propagation environment, service mix, traffic characteristics, spatial traffic distribution, quality and grade of service requirements, and then raise the aggregate call arrival rate until the quality/grade of service requirements can no longer be met.

One simple example is to apply the Erlang loss model to a single GSM cell. If we assume a resource availability of 29 traffic channels and a maximum blocking probability of, say, 2%, ‘inversion’ of the Erlang loss formula yields a maximum allowed traffic load of 21.0 Erlang. Note that the definition of Section 2.1.3.1 would yield a capacity of 29 concurrent calls. Another example in the context of HSDPA networks can be found in [10].

2.1.3.3 Spectrum efficiency

The spectrum efficiency is very closely related to the first capacity measure. Following the same approach and having obtained the maximum number of concurrent calls per cell, the spectrum efficiency is equal to the corresponding aggregate net bit rate per cell, divided by the system bandwidth. For example, if a single carrier (5 MHz) HSPA cell evaluated in a study like [8] and [9] can support up to a maximum of 50 VoIP calls per cell, each with an information bit rate of 64 kb/s and an experienced frame error rate of 1%, the spectrum efficiency is \( 0.99 \times 64 \times 50 / 5 = 633.6 \text{ kb/s/MHz/cell} \).

2.1.4 Revenue

In the present context, revenue is defined as the amount of money per unit of time earned by the network operator (service provider) by selling services to customers. In practice, different charging schemes exist, varying from flat fee schemes to charging a service-specific amount per transferred bit, and it depends on the applied charging scheme how revenues are affected by the deployment of self-organisation methods.

The reason we need a model for determining revenues is to assess, besides OPEX and CAPEX, also the monetary advantages of gaining ‘otherwise missed revenue’ when applying self-healing principles to enhance service availability in case of cell outages. In order to quantify this ‘otherwise missed revenue’, the following approach is used, illustrated by Figure 2. This approach is based on a simple uniform bit-based charging scheme.

Consider two scenarios, one with and one without self-healing functionality (in the example this comprises both cell outage detection and cell outage compensation). At some point in time an eNB ‘dies’ (is in outage). In the case without self-healing, it takes some amount of time before the outage is manually detected, after which it takes some ‘repair time’ until the eNB is up and running again. In the figure it is assumed that during both the ‘detection time’ and the ‘repair time’ no local revenues are gained, although alternatively, one may assume some degree of manual outage compensation, in which case some revenues are made during the ‘repair time’.

In the case with self-healing, the detection time is reduced to (virtually) zero due to the automated cell outage detection algorithm. Moreover, during the ‘repair time’ some amount of traffic can still be locally handled due to the measures taken by the cell outage compensation algorithm, yielding some level of revenue. Although this is not assumed in the figure, it is noted that the repair time may even be shortened compared to the case without self-healing, if the cell outage detection algorithm speeds up the repair by indicating the nature of the problem. Depending on the assumptions regarding manual cell outage compensation and possible reduction of repair times due to (automated) cell outage detection, the ‘otherwise missed revenue’ is indicated in Figure 2, i.e., the amount of additionally handled traffic.
multiplied by the revenue per bit. It is noted that in such scenarios the revenue should be assessed not on a per cell basis, but rather on a regional (in the figure, ‘local’ refers to a regional area) basis, in order to capture the local compensation effect properly.

Figure 2: Gaining the ‘otherwise missed revenue’ of the case without self-healing in the case with self-healing.

As a final note, in case flat fee charging is applied, the revenues do not directly depend on the handled traffic and the ‘otherwise missed revenue’, as indicated in the above reasoning, is effectively 0. In general, however, there may still be an indirect effect of the deployment of self-organisation on revenue which applies also under flat fee charging. This indirect effect is related to the churn effect, where customers prefer operators that provide better service and/or lower rates. To be specific, if self-healing methods improve the availability of services, the network operator may attract new customers and keep existing customers, with an obvious effect on revenue. To conclude, it is noted that the customer behaviour at this point and hence this effect on the revenue is hard to evaluate quantitatively.

2.1.5 CAPEX

2.1.5.1 Introduction

In general, CAPEX encompasses the investments needed in order to create future benefits, which includes Radio Access Network (RAN) equipment (eNodeB), core network (MME and S-GW), transmission and transport network (e.g., Ethernet and microwave networks), service layer, equipment roll-out (e.g., integration and testing and in-house solutions), and construction (e.g., site acquisition and civil works). In general there are tradeoffs between QoS and/or GoS, and CAPEX. Typically, QoS and GoS decrease with increasing site-to-site distance. This results in decreased CAPEX since an increasing site-to-site distance implies fewer RAN and transport network equipment.

An approach to estimate the number of network elements (RAN equipment) needed to satisfy requirements on QoS and/or GoS is presented in Section 2.1.5.2. This approach is strongly related to the capacity definitions in Section 2.1.3. The introduction of SON may increase the cost of network elements and this will be discussed in Section 2.1.5.3. A methodology for assessing self-organisation algorithms based on their overall CAPEX savings is presented in Section 2.1.5.4.

2.1.5.2 Estimating number of network elements

Key component of the overall CAPEX is the purchase of network elements, in particular the base stations, needed to provide sufficient capacity. Given this inherent relation between CAPEX and capacity, the proposed approach to estimate the CAPEX is strongly related to the capacity definitions given in Section 2.1.3.
Starting point of the approach, besides assumptions regarding propagation environment, service mix, traffic characteristics, spatial traffic distribution, quality/grade of service requirements, is an assumption regarding the traffic demand per km$^2$. The approach is most readily formulated and implemented if we assume spatially uniform traffic demand and hence apply hexagonal network layout. The idea is then to start with a widely stretched network with very large cells, and compress this layout until the cells are just small enough to handle the correspondingly captured traffic load with sufficient grade/quality of service (see Figure 3). The thus obtained cell area is then easily applied to determine the number of base stations that is needed to cover a given service area, e.g., The Netherlands. Multiplying this number with an assumed typical price of a base station gives us an estimate of the base station-related CAPEX. Given some a priori agreed ratio of supportable base stations per other network element (e.g., MMEs), and the associated purchasing price, we can extend the CAPEX estimate to cover other network elements as well.

![Figure 3: Compression of network with large cells and poor GoS/QoS into a network with an optimal cell size wrt GoS/QoS.](image)

It is noted that the proposed approach can in principle be applied for any of the above-described capacity definitions, as long as the traffic demand per km$^2$ is expressed in corresponding units. For instance, in case of the ‘Maximum supportable traffic load’ capacity definition, the capacity is expressed in a supported maximum aggregate call arrival rate per cell, and hence the traffic demand per km$^2$ should then also be expressed in terms of a call arrival rate per km$^2$. An example of this approach is given in [11].

One outcome of self-optimisation may be a decrease in CAPEX since less number of sites or cells may be needed to provide the same QoS and/or GoS as a non-optimised network. Self-organisation may result in enhancements in QoS and/or GoS and, consequently, an increase in the site-to-site distance and less investment in equipment for capacity extension compared to a non-optimised network.

Another aspect is that SON, e.g., by avoiding incorrect operations or by temporarily switching off unused cells or antennas, might positively impact the average lifetime of the equipment. In order to capture changes in lifetime an average lifetime of the equipment should be deduced in both cases if possible and the required CAPEX per year should be compared. Of course, such effects might be hard to quantify in the current research phase, but at least this aspect should be discussed qualitatively.

2.1.5.3 Impact of SON on CAPEX

The introduction of self-organisation (configuration, optimisation, and healing) may, however, also result in increases in equipment cost. This depends on the self-organisation algorithm and a set of factors associated with the algorithm such as computational complexity, network bandwidth requirements to other nodes (over, e.g., X2 and S1), and additional costs related to needed site equipment, e.g., electrical antenna tilt (which is often omitted due to cost savings), and additional circuitry for enabling power savings.

In general, the computational capability (hardware) of a cell or site needs to be dimensioned according to the offered traffic. With the introduction of self-organising algorithms the computational capabilities of eNodeBs must also encompass self-organisation algorithms executing in the eNodeBs. The execution time of a particular algorithm typically depends on the size $n$ of the input data, e.g., number of measurements, and can be asymptotically logarithmic ($\log n$), polynomial ($n^p$), or even exponential ($a^n$).

\[1\] A similar argumentation can be used for OPEX in case SON functionality increases the required service intervals.
An analysis of asymptotic execution time gives an insight in the processing demand of an algorithm. In addition, self-organisation algorithms may require extensive network monitoring in order to ensure that these algorithms are operating well. Reports and counters need to be sent to OSS over the backhaul. A self-organisation algorithm may also interact heavily with other nodes in the network (e.g., other eNodeBs) resulting in higher transmission costs. Ideally, these aspects must also be taken into account when evaluating CAPEX savings. The underlying assumption is, however, the savings due to reduced number of sites and RAN equipment is larger than corresponding increases in equipment costs due to additional complexity.

2.1.5.4 Overall analysis of CAPEX

Estimating savings due to enhanced QoS and/or GoS, and increases in equipment cost due to additional software running on the eNodeBs may be difficult to quantify exactly. Instead we have to resort to approximations or qualitative assessments. The following metrics can be used when assessing the CAPEX saving as a result of introducing a particular self-organisation algorithm. Here we assume that a network without self-organisation is configured with a set of default or standard parameters yielding acceptable performance.

- The number of sites or cells needed to cover a certain area served by a network with and a network without self-organisation. A cost associated with a site or cell may be used to estimate CAPEX savings.
- The number of sites or cells needed to provide a certain QoS in a given area served by a network with and a network without self-organisation. A cost associated with a site or cell may be used to estimate CAPEX savings.

The following issues should be considered when assessing increases in equipment costs. Since associating a cost with the issues given below is difficult (if feasible at all), a qualitative assessment should be carried out considering:

- The estimated execution time, i.e., to determine the asymptotic execution time of an algorithm.
- The estimated bandwidth, i.e., to determine the bandwidth required over the transport network to other eNodeBs, MME/S-GW, and OSS. This can be estimated in terms of the number of packets sent and the estimated payload of each packet.
- The need for additional equipment, e.g., electrical tilt.

The third issue mentioned above (need for additional equipment), requires an understanding of what RAN functions are typically optional and may be purchased if needed.

The CAPEX savings and expenses listed above should be used as input to form an overall assessment of CAPEX savings associated with a particular self-organisation function. For example, if two self-organisation algorithms perform equally in terms of reduced number of needed sites, then execution time and bandwidth requirements may serve as indicator for determining which of the two algorithms performs best in terms of CAPEX savings.

2.1.6 OPEX

2.1.6.1 Introduction

In this section, a method is presented for determining OPEX reductions for SON. First, in Section 2.1.6.2, a method is presented for determining OPEX for network operations and optimisation processes, for the case that SON is not used. The processes used by a typical mobile network operator are considered, and different aspects of each of these processes are analysed. Next, in Section 2.1.6.3, a method is presented for determining OPEX for the case that SON is used. In Section 2.1.6.4, some information is provided on how the calculated OPEX values can be used.

2.1.6.2 Method for determining OPEX without SON

To determine OPEX without SON, various phases related to network operations and optimisations are considered. A model is developed that determines OPEX values for all steps in each phase. The total OPEX is then determined by adding together all components.

The intention is that this method is applied to all SON use cases. However, to consider OPEX without SON, it does not make sense to consider the SON use case itself. Instead, the manual equivalent of the
SON use case should be considered. For example, the handover parameter optimisation use case considers automatic adjustment to handover parameters. For the purpose of determining OPEX without SON, efforts to manually adjust handover parameters should be considered.

For some use cases, it may not be possible to determine OPEX without SON, because these use cases are only possible with SON. An example of such a use case is load balancing, which requires continual changes to the network (in theory this could be done manually, but would require a huge effort to monitor all cells in the network - in practice no operator would do this). For such use cases, considering OPEX reductions is not useful, and performance should be measured using other metrics.

Three main phases are defined for parameter adjustments:

A. **Obtain input data**: Gaining information needed for parameter adjustments.

B. **Determine new parameter settings**: Using the input data to determine new settings. Various approaches are possible for doing this (and will be considered in the text below).

C. **Apply new parameter settings**: The process of transferring the new settings into the network.

**A. Obtain input data**

There are three methods for obtaining input data:

1. Information available in planning tools
2. Measurements directly obtained from the network (i.e., performance counters)
3. Drive tests

For the considered use case, it should be determined which of these apply (combinations of these methods are also possible). Then, for each method, the total effort expressed in number of days should be estimated.

**B. Determine new parameter settings**

For the assessment of OPEX reductions, four categories of parameter adjustments are defined:

1. Purely manual parameter adjustment
2. Computer-assisted parameter adjustment using network measurements (either from the network or by means of drive tests)
3. Computer-assisted parameter adjustment using a planning tool
4. Computer-assisted parameter adjustment using an advanced simulation model

For each use case, it should be determined which of these categories apply (combinations of different categories are also possible).

**B.1. Purely manual parameter adjustment**

Straightforward parameter adjustments that can be made by an expert network engineer. Decisions to make parameter changes will be based on previous experience of adjusting parameters. The manual effort to determine new parameter settings will be small, as no detailed analysis will be required. However, there will be effort involved in gaining the experience to make these adjustments, and that should also be taken into account.

**B.2. Computer-assisted parameter adjustment using network measurements**

Measurements can be obtained either directly from the network itself, or by means of drive tests. The results of the measurements will be loaded into analysis tools. Data can then be statistically processed or plotted.

Effort required should be estimated for these components:

- Analysis of data
- Determine new parameter settings

**B.3. Computer-assisted parameter adjustment using a planning tool**

Using site and geographic data available in the planning tool, the network configuration is manually optimised. For example, the effect of parameter changes on coverage can be studied by using coverage predictions.

**B.4. Computer-assisted parameter adjustment using an advanced simulation model**
Using computer models of the network, determine parameter settings that will improve performance. Effort required should be estimated for each of these three components (assuming a simulation/optimisation model/tool is available and already suitable for the purpose):

- Define scenario to be simulated
- Evaluate results of analysis
- Determine optimal parameter settings

Results should be total effort in number of days to determine parameter adjustments for the specific use case.

If it is found that SON completely removes the need for an advanced simulation model, the associated reduction in CAPEX/OPEX for buying/developing such a tool should also be taken into account.

C. Apply new parameter settings

New parameter settings can be transferred into the network using two methods:

1. Parameters transferred by automatic processes
2. Parameter adjustments requiring a site visit. Examples of such parameters are mechanical antenna tilt and azimuth.

The result of the analysis of phases A, B and C will be effort in number of days. Calculation of the total OPEX then requires two further steps:

I. Cost per individual adjustment: Convert effort into cost in Euro.

II. Total yearly OPEX for the use case: Determine total OPEX, for a whole network (countrywide), over a year.

I. Cost per individual adjustment

Using the estimated values for required effort for each activity, as proposed in the above sections, it is possible to determine the total cost for an individual adjustment:

\[
\text{Total cost per individual adjustment} = \sum_{\text{Effort types}} \text{Effort in number of days} \times \text{Cost per day}.
\]

Most likely, the types of cost will be:

- Cost per day of an operations/optimisation expert
- Cost per day of drive tests

Costs should be expressed in Euro.

II. Total yearly OPEX for the use case

For each adjustment type:

\[
\text{OPEX / year} = \text{Cost per individual adjustment} \times \text{Multiplication factor to apply adjustment to whole country} \times \text{Number of times per year that adjustment is required}.
\]

The multiplication factor in the above equation will depend on the nature of the adjustment. One extreme is if a new parameter value has been determined, and the same parameter value can be applied to all base stations in the country, then the multiplication factor is 1. The other extreme is that a new parameter value has to be determined, that is different for each base station. If there are 1000 base station in the country, then the multiplication factor will be 1000 (this assumes that adjusting the parameter for 1000 base stations requires a factor 1000 times more effort than adjusting the parameters for just 1 base station). In between these two extremes, there may be cases where a new parameter value is applied to all base stations in a region, but different values are applied to different regions. This should be combined with an estimate of how often parameters will be updated, resulting in OPEX per year.

For each use case, there may be different adjustment types, for example, if more than one parameter gets optimised by the use case. Different parameters may also be optimised differently – some may be adjusted for each cell, while others may be set for the whole network. The total OPEX for the use case, taking into account all adjustments related to the use case is:
Total OPEX / year = \sum_{\text{All adjustment types}} \text{OPEX} / \text{year}.

It is recognised that this model is a simplification of the reality of how costs occur. Particularly, the following should be noted:

- In reality, the link between efforts and cost may not be linear. For example, it may be necessary to have staff available to monitor the network 24/7, independent of how often changes are required.
- In reality, the link between effort per cell and effort for a whole country will not be linear. For example, the drive time to a cell will vary greatly depending on where a cell/eNodeB is located.
- Total OPEX / year will vary depending on the phase of network deployment. The OPEX will most likely be the highest during the initial roll-out phase.

However, for a comparative analysis of systems with and without SON, and for comparing different algorithms, the model is appropriate.

2.1.6.3 Method for determining OPEX with SON

In the previous section, a method was presented for determining OPEX for a use case where SON is not applied. To determine OPEX with SON, the same process should be applied as in the previous section. However, for each component contributing to the total effort, the impact of SON on this effort should be determined. For some components the effort will be reduced to nothing, while for others it will be partially reduced. It is essential that the assessment of the impact on effort will be based on the properties of the developed solution. For example, if one of the components for effort without SON is drive tests, and the SON solution completely removes the need for drive tests, effort for this can be set to 0.

Examples of questions to consider when determining OPEX with SON:

- Can the algorithm automatically detect the problem? If it cannot do this completely automatically, what manual effort is still required?
- Can the algorithm automatically determine the cause of the problem? If it cannot do this completely automatically, what manual effort is still required?
- Can the algorithm automatically resolve the problem? If it cannot do this completely automatically, what manual effort is still required?

The answers to these questions will help determine how much the effort is reduced for each of the components contributing to the total effort.

2.1.6.4 Analysis of OPEX reductions

Detailed analysis of how to use the OPEX calculations for overall benchmarking is provided in Section 2.2. In this section some information is provided on how the calculated OPEX values can be used.

The results of the method presented in the previous two sections will be a value for the OPEX without SON, and a value for the OPEX with SON. Both values are for one use case. It is also possible that there will be multiple values for OPEX with SON, if multiple solutions are considered. In addition it is possible that there are multiple values for OPEX without SON, if different manual optimisation approaches are considered.

To ensure that the comparison is fair, it is important that for all OPEX values, the network quality and CAPEX remain the same. This may be hard to achieve, and if it is not possible to maintain constant network quality and CAPEX, this should be taken into account in the benchmarking (see Section 2.2). For example, if the OPEX is reduced for the case with SON, but the network quality is also lower, then that is not a good comparison.

Application to self-configuration

The methods for determining OPEX as described in the above sections can be applied to self-configuration use cases.

Application to self-optimisation

The methods for determining OPEX as described in the above sections can be applied to self-optimisation use cases. However, for some of the self-optimisation use cases it is possible that manual optimisation is not applied, and therefore there OPEX is zero for the case without SON. For those cases, improvements in network quality and reductions in CAPEX should be considered, rather than reductions in OPEX.
Application to self-healing
The methods for determining OPEX, as described in the above sections, can, in principle, be applied to self-healing. However, considering the impact on revenue is potentially more useful. See Section 2.1.4 for details about the effect on revenue.

How much impact self-healing will have on OPEX, depends on how much manual compensation is applied when cell outage occurs. In addition, OPEX may be reduced by the fact that less manual effort is required to determine the cause of the cell outage.

2.1.7 Other metrics
It should be noted that several of the metrics considered in the current section are subordinate to the performance metrics in the sense that e.g., slow algorithm convergence will have a negative impact on e.g., GoS/QoS.

The metrics in this section are also considered as technical requirements in the SOCRATES deliverable D2.2 [2]. Hence an important part of the assessment is whether these requirements are met by the developed solutions.

2.1.7.1 Stability
Associated effects (e.g., oscillations) are observed via performance metrics. No direct quantification of stability is possible. However, a qualitative analysis is possible.

2.1.7.2 Convergence time
Convergence time is defined as the time it takes from the moment SON decides that environment changes demand parameter adjustment, until the time when the new parameter settings are final (for the current environment characteristics). Note that, depending on the algorithm, determining the new parameters could be a one shot procedure or an iterative process of incremental changes. This should be assessed by comparing the convergence time from the requirements to the convergence time achieved by the solution.

2.1.7.3 Complexity
Complexity consists of the following elements:
- Convergence time (see Section 2.1.7.2)
- Required hard/software
- Requirements on standardisation
- Strain on terminal equipment (including energy consumption)
- Measurement gathering
- Processing

Some of this is also covered under e.g., overhead or CAPEX. As it will be difficult to do an exact quantitative assessment, a qualitative analysis should be considered.

2.1.7.4 Overhead
Ideally of course, the overhead on the radio interface (in terms of e.g., measurement gathering) is explicitly considered in the simulation, and will hence affect the resources remaining for actual traffic handling and therefore the achieved GoS/QoS, capacity, etc. Alternatively, we may not explicitly simulate the overhead but estimate its load off-line. In that case, overhead should be considered together with the performance criteria.

In addition, overhead on the backhaul network should also be considered.

2.1.7.5 Robustness
In general, assessment of the SON solutions will be based on the assumption that all parts of the system are functioning correctly. However, in reality, there may be wrong or missing data. This should be modelled in simulations, and robustness can then be evaluated by comparing simulations with and without wrong/missing data.
2.2 Benchmarking as an assessment approach

One of the project objectives is to do a mutual comparison of different self-organisation methods developed for a given use case, and moreover to compare their achieved performance, capacity, cost, revenue, to the case with manual network operation.

In this section, we describe an approach for such benchmarking. The approach is primarily outlined from the perspective of a self-optimisation use case, while at the end some comments are made regarding self-configuration and self-healing use cases.

Starting point is a specific scenario in terms of e.g., the propagation environment, service mix, traffic characteristics, spatial traffic distribution. For such a scenario, the achievements of the different developed self-optimisation algorithms comprise measures of e.g., performance, complexity and CAPEX, and are further characterised by the number of parameter adjustments that are made per time unit which is a key contributor to the OPEX (see Section 2.1.6).

The example Figure 4 below visualises fluctuations in the traffic / mobility / propagation characteristics, and the algorithm-specific timing of induced radio parameter adjustments.

![Figure 4: Fluctuations in traffic / mobility / propagation characteristics, and the algorithm-specific timing of induced radio parameter adjustments.](image)

In Figure 5, example values of the performance indicators obtained at the end of the simulations are shown. Observe that e.g., self-optimisation algorithm SOA achieves the highest performance, which can be exploited to achieve the lowest CAPEX, but in order to achieve this it requires a lot of measurements (~ complexity) and parameter adjustments per time unit (~ OPEX in case of manual optimisation; it is noted that the ‘OPEX’ bar in the figure indicates the associated OPEX in the ‘manual’ equivalent of the self-optimisation algorithm, i.e., the ‘saved OPEX’). In contrast, algorithm SOD is significantly less complex but consequently achieves worse performance and CAPEX.

![Figure 5: Example values of obtained performance indicators.](image)

In general, it is hard to compare SOA through SOD given the conflicting performance objectives, e.g., SOA outperforms SOD in terms of CAPEX, but SOD outperforms SOA in terms of complexity. One 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. Another approach is to select one measure as single target measure, place constraints on the other measures and rank only those algorithms that meet the constraints on the other measures based on the target measure.

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. For such a comparison one needs to specify the manual optimisation method, in order to derive estimates for the different performance, capacity, etc., measures.
In an extreme case, we could assume that a ‘manual operator’ freezes its radio parameters once and for all. In that case it would make sense to do an off-line optimisation of the parameter set such that the overall performance is optimised, considering the given scenario with varying traffic / mobility / propagation characteristics.

In practice, however, a network operator will monitor such characteristics as well as the achieved performance level, and occasionally redetermine 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’ MOA through MO D (continuing the above example) such that they manually adjust radio parameters at the same time and to the same values as the corresponding self-optimisation algorithms with the same label. An example comparison of SOA with MO D is visualised in Figure 6, concentrating on (for example) CAPEX and OPEX-related measures.

Assuming that self-optimisation reduces OPEX to zero\(^1\), the OPEX gain achieved by self-optimisation is indicated by the height of the OPEX bar associated with the MO D algorithm. In order to convert this measure to a monetary value, one needs to assume some amount of effort involved in a radio parameter adjustment, which may be estimated by a network operator. In this light, we also note that it may be wise to distinguish between different types of parameter adjustments that involve different degrees of manual effort. The CAPEX gain is trivially indicated by the difference in the algorithms’ CAPEX values.

Following this approach for different combinations of SOA and MOY we could generate tables such as Table 2, where the ‘+’, ‘-’ and ‘0’s are just qualitative indicators; actual numerical values should be determined via the simulation studies. Observe that introducing self-optimisation in the network of quality-oriented operator is likely to establish the highest OPEX gains, but the lowest CAPEX gains.

We finalise this subsection with some comments about benchmarking for self-configuration and self-healing use cases, noting again that the above approach was primarily outlined from the perspective of self-optimisation use cases.

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\(^1\) The assumption that the manual optimisation algorithm makes the same adjustments at the same time is easily relaxed in an actual quantitative study, e.g., by introducing randomised discrepancies in the (timing of) parameter adjustments.

\(^2\) This assumption may need to be relaxed somewhat, since even self-optimised networks will require some human involvement in terms of performance monitoring, sanity checking, etc. In any case, for the purpose of explaining the approach this assumption is acceptable.
Regarding self-configuration, the OPEX gain can be estimated by consulting one or several network operators what human effort is required for the different subtasks that are involved. See also related comments in Section 2.1.6. Depending on the set of subtasks that is automated by self-configuration methods, the OPEX gain can be determined. We expect that no significant CAPEX gains are achieved from self-configuration. In terms of performance and revenue, there may be a gain due to improved GoS/QoS and correspondingly, possible increased revenue. This is however less likely if the deployment of new sites or features is done at night, which is typically the case.

Regarding self-healing, including cell outage compensation, there may be some OPEX gain if the cell outage detection mechanism speeds up the problem identification and if the cell outage compensation is automated, which would otherwise be done manually. Still, most OPEX is related to actually fixing the failed site, which will remain even with self-healing. The impact of self-healing on the GoS/QoS and the associated revenues was already discussed in Section 2.1.4. In terms of CAPEX gain, we can see this originate from a need for less redundancy to cope with potential failures (in a typical network, however, such redundancy is not used in the radio interface) or potentially even from a reduced requirement on eNB reliability, although this may not the recommended way to exploit the gains from self-healing.

2.3 Application of metrics and benchmarking to some use cases

In this section, the application of the metrics and benchmarking discussed before is considered for three example use cases. Objective of doing that is to determine whether the metrics and benchmarking approach is suitable for the SOCRATES use cases. A self-configuration use case (intelligently selecting site locations) is considered in Sections 2.3.1 and 2.3.2, a self-optimisation use case (packet scheduling parameter optimisation) is examined in Sections 2.3.3 and 2.3.4, and in Sections 2.3.5 and 2.3.6 a self-healing use case (cell outage compensation) is treated. A definition of these three use cases can be found in the SOCRATES deliverable D2.1 [1].

2.3.1 Application of the metrics to the intelligently selecting site locations use case

The application of the assessment criteria to the intelligently selecting site locations use case is considered here. In this section, intelligently selecting site locations is assumed to include the identification of the need for a new base station, and the selection of an area where that base station will be added.

An overview of the applicability of metrics for this use case is given in Table 3.

2.3.1.1 Performance (GoS/QoS)

The useful metrics for this use case are:

- Call blocking ratio
- Call dropping ratio
- Call success ratio
- Packet delay
- Transfer time
- Throughput
- Packet loss ratio
- Mean opinion score

All of the above metrics can be used to assess the impact on performance, as adding a new site will most likely result in an improvement for all of the above metrics. However, the intelligently selecting site locations use case itself will not directly have an impact on performance. But if the network operator decides to add a base station based on the output of this use case, then that will improve performance. A possible procedure for assessing that impact is:

- A scenario is simulated where part of the network is overloaded. The scenario is based on a real network.
- As a result of this, the expected output of the use case is a proposed area in which to add a new base station
- The next step is then to manually select an exact location for the new base station (based on building locations, heights etc.)
The simulation is then re-run with the new base station added to the network.

Performance is compared with and without the new base station.

Using call blocking ratio as an example: the network operator will have a target value for call blocking ratio; for example, it must be less than 2%. The decision to add a new base station may be based on the fact that call blocking ratio increases above 2%. If as a result of adding the new base station, this call ratio drops below 2% again, then the result of the assessment is that the use case has been successful. Similar considerations apply to other performance metrics.

The main objectives of the assessment are:

- Does the algorithm correctly detect the need for a new base station? The two potential issues are:
  - Algorithm detects the needs for a new base station, when a new base station is not needed
  - Algorithm does not detect the need for a new base station, when a new base station is needed

- Given the proposed area, is it possible to select an exact location that results in satisfactory improved network performance?

In addition, it may also be interesting to consider the difference in performance between a network that is planned without applying this use case (but possibly still using some off-line tools), and a network that is planned with this use case.

### 2.3.1.2 Coverage

The useful metrics for this use case are:

- SINR coverage
- Data rate coverage
- Combined coverage and capacity index

The combined coverage and capacity index metric is the most realistic, but it may be simpler and more practical to use the data rate coverage metric.

Obviously, if a new base station is added in an area where there are coverage problems, coverage will be improved. However, there may also be scenarios where the requirement for a new base station is purely based on capacity.

The same applies here that applies to other metrics: what is the difference between applying this use case, and a manual process for adding new sites? Will coverage improve earlier, or more?

### 2.3.1.3 Capacity

The useful metrics for this use case are:

- Maximum number of concurrent calls
- Maximum supportable traffic load
- Spectrum efficiency

Capacity can be considered on two levels: per cell, or over a whole area. Adding a new base station will not increase the capacity per cell. In fact, it may reduce the capacity per cell, as there may be more intercell interference. However, the capacity over the whole area should increase, as there are more base stations.

The exact definition of the evaluation area is important to assess the impact on capacity correctly, since choosing a too large area might result in the effect being hardly visible. A reasonable assumption might therefore be to use the area covered by the cells that are impacted by the insertion of the new node. This can be evaluated by comparing the respective cell throughput figures before and after insertion of the new node. Typically the impacted area might extend over one or two tiers of surrounding cells.
2.3.1.4 Revenue
Adding a base station should result in extra revenue from traffic on the new site. However, this will be very difficult to assess, and therefore this metric is considered unsuitable for this use case.

2.3.1.5 CAPEX
The effect on CAPEX will depend on what the reference is. Obviously, if you add a base station as a result of this use case, when you would not have done so anyway, that will mean an increase in CAPEX.
The assessment of CAPEX should be done while also taking into account other metrics, i.e., network performance/quality/capacity and OPEX. The comparison should be between making decisions on where to add sites based on conventional procedures (network planning tools etc.), and based on the intelligently selecting site locations use case. Site selection based on the SON use case may result in a better selection of where sites are needed, and may avoid adding sites that are not necessary. Overall, if fewer sites are needed as a result of this use case, then that means less CAPEX.

2.3.1.6 OPEX
To assess the impact of this SON use case, the current steps for selecting sites should be determined. For each of these steps, it should be evaluated which steps are no longer needed as a result of the SON use case.

2.3.1.7 Other metrics
The useful metric for this use case is:

- Complexity

Complexity will include aspects such as processing required, standardisation issues, etc.

2.3.2 Application of benchmarking to the intelligently selecting site locations use case
Final assessment should be based on a combination of the assessment criteria considered in the above sections. The appropriate reference case for the manual approach will depend on the approach of the operator. For a quality-oriented operator, the manual case would be that network performance is monitored, and data is analysed to determine when new base stations are needed. For a cost-oriented operator, the manual case would be that only planning tools are used, and that performance is not monitored.

2.3.3 Application of the metrics to the packet scheduling parameter optimisation use case
The application of the assessment criteria to the packet scheduling parameter optimisation use case are considered here. An overview of the applicability of metrics for this use case is given in Table 3.

2.3.3.1 Performance (GoS/QoS)
The useful metrics for this use case are:

- Call blocking ratio: For the same load, the optimisation algorithm should reduce call blocking ratio. Therefore, this is a useful metric, to quantify the difference in blocking.
- Call dropping ratio: For the same load, the optimisation algorithm should reduce call dropping ratio. Therefore, this is a useful metric, to quantify the difference in dropping.
- Call success ratio: This is a combination of blocking and dropping ratio, and can be used in addition to these.
- Packet delay: The optimisation algorithm should reduce packet delay. Therefore, this is a useful metric, to quantify the difference in delay.
- Transfer time: Although it does not really provide additional information beyond what is provided by throughput, it is a more user-oriented method of assessing performance.
- Throughput: Algorithm should increase throughput. Therefore, this is a useful metric, to quantify the difference in throughput. CDF of throughput should be considered, as it may vary strongly depending on where in the cell the user is located.
• Fairness: An important metric to consider for a scheduler, as the scheduler has a strong impact on this.

• Outage: for each service, the criteria should be defined which determine when the service is in outage. Outage can then be used for assessment.

For the algorithm, it will have to be decided, which of these performance criteria should be used. If multiple criteria are used, it will most likely be necessary to run separate simulations for these criteria.

A possible simulation set up to assess user throughput is a fixed number of users with full buffer data in each cell. First, the scheduler without SON is considered, then with SON. The difference in throughput for these two cases can then be assessed. In this example, to ensure a fair comparison, blocking and dropping should be switched off, as it is important that the number of users per cell remains constant.

In contrast, to assess blocking probability, users with a constant bit rate service could be used. The blocking probability should then be compared for the cases with and without SON for the scheduler. In both cases the QoS that the users are experiencing should remain the same.

For both these examples, it is essential that for the scheduler without SON appropriate ‘reference’ parameters are used for the scheduler.

2.3.3.2 Coverage
It is not expected that packet scheduler optimisation will have a (significant) impact on coverage, and it is therefore not a useful metric for this use case

2.3.3.3 Capacity
The useful metrics for this use case are:

• Maximum number of concurrent calls

• Maximum supportable traffic load

To assess capacity, the total number of concurrent calls should be assessed for a selection of services and service mixes. Using just a single service makes it easy to determine the number of concurrent calls, and to compare different optimisation algorithms. However, an important aspect of a scheduler is its ability to handle a variety of services, each with their own QoS requirements. As a result it is necessary to assess capacity for a service mix. For example, consider a scenario with service A and service B. A fixed number of users of service A are included in the simulation. Then users of service B are added until the cell is considered fully loaded. Different algorithms can then be compared on how many users of service B are supported.

For the scheduler, fairness should also be taken into account when considering capacity. For example, a cell may have a high total traffic load, but this may be due to a small number of users close to the base station that are achieving a very high throughput. Users that are close to the cell edge may experience a very low throughput. Therefore, requirements for fair distribution of throughput over the whole cell area should be considered when assessing capacity.

2.3.3.4 Revenue
If SON functionality in the scheduler results in better GoS/QoS, this will potentially result in more usage of the service, which in turn results in more revenue. However, the impact of this is very difficult to assess. It is therefore recommended not to use this metric.

2.3.3.5 CAPEX
If there is a capacity improvement due to scheduler SON, this will mean that fewer base stations are required.

Impact on hardware cost of adding scheduler SON functionality is difficult to determine.

2.3.3.6 OPEX
SON could potentially adjust scheduler parameters in the order of minutes or hours. This type of optimisation cannot be achieved manually.

Manual adjustment of scheduler parameters will generally occur infrequently. Scheduler parameters are also likely to be the same for all cells in an area.
2.3.3.7 Other metrics

The useful metrics for this use case are:

- Stability
- Convergence time
- Complexity
- Overhead
- Robustness

Although the impact of the above criteria should be noticeable in the performance metrics, it is still useful to assess them separately. Such an assessment would be mainly qualitative rather than quantitative. However, if overhead is not explicitly modelled, a separate quantitative assessment of its impact will be required.

2.3.4 Application of benchmarking to the packet scheduling parameter optimisation use case

For comparison purposes, for the packet scheduling optimisation use case, the assessment of improvements in GoS/QoS is probably the most important criterion to use. However, when determining absolute gain, other criteria (complexity, OPEX, CAPEX) should also be considered.

For GoS/QoS, it will be necessary to determine to combine several metrics into a single value. The appropriate reference case for the manual approach will depend on the approach of the operator. For a quality-oriented operator, the manual case would be that optimal parameters are determined manually for a typical traffic and service mix. These parameters are applied to all cells. For a cost-oriented operator, the manual case would be that no manual optimisation is done, and only default parameters are used.

2.3.5 Application of the metrics to the cell outage compensation use case

The application of the assessment criteria to the cell outage compensation use case is considered here. An overview of the applicability of metrics for this use case is given in Table 3.

2.3.5.1 Performance (GoS/QoS)

The useful metrics for this use case are:

- Call blocking ratio: The network situation will change dramatically due to a cell outage. It is most likely that coverage holes and lack of capacity will be the consequence of a cell outage. In the uncovered areas the blocking ratio is defined as 100% for this assessment metric. It is the aim of the cell outage compensation to cover the uncovered area again if possible. Furthermore the user access attempts for broadband applications will be blocked to decrease the blocking ratio and increase the cell capacity for voice services. Hence for the same load, the optimisation algorithm should reduce the call blocking ratio in the cell outage area. It may happen that the blocking ratio goes up for UEs in neighbouring cells. The blocking ratio should not exceed certain thresholds.

- Call dropping ratio: As defined for the blocking ratio metric before, the call dropping ratio is defined to be 100% in the uncovered areas. After the compensation the call dropping ratio should decrease due to the described compensation activities. Hence for the same load, the optimisation algorithm should reduce dropping ratio in the cell outage area. It may happen that the dropping ratio goes up for UEs in neighbouring cells. The dropping ratio should not exceed certain thresholds.

- Call success ratio: This is a combination of blocking and dropping ratio, and can be used in addition to these.

- Packet delay: If a cell is in outage the network performance is decreasing significantly in the cell outage area due to this new network situation. The packet delay may increase due to higher traffic load for the neighbouring cells. The packet delay should not exceed certain thresholds.
• Transfer time: Although it does not really provide additional information beyond what is provided by throughput, it is a more user-oriented method of assessing performance.

• Throughput: The throughput will most likely decrease in a cell outage situation due to the uncovered areas and lack of capacity caused by the cell outage. The throughput is defined to be 0 in the uncovered areas for this metric. After the compensation activities the user throughput will increase in the formerly uncovered areas if the algorithm is working correctly, i.e., parts of the uncovered area are covered again. The cell throughput for the neighbouring cells may decrease due to significant changes in these cells, e.g., other modulation scheme (4 QAM instead of 64 QAM) or higher interference due to higher output power. It will be impossible to hold up QoS / GoS levels for the cells influenced by the cell outage compensation.

• Packet loss ratio: If a cell is in outage the network performance is decreasing significantly in the cell outage area due to this new network situation. The number of packet losses may increase due to higher interference in the neighbouring cells after the compensation. The number of packet losses should not exceed certain thresholds.

• Mean opinion score: The cell outage compensation should prioritise voice services in such a way that the required (minimum) MOS score is achieved and more user access attempts are operated than before the compensation activities. Since the MOS may increase during the cell outage compensation this metric is considered to be a weak assessment criterion for this use case. The MOS should not exceed certain thresholds.

• Fairness: Fairness is an important assessment criterion for the cell outage compensation since the network resources are limited due to the cell outage situation. It is the aim of the cell outage compensation to distribute the remaining network resources fairly among all users. This applies to several of the performance metrics, e.g., throughput.

• Outage: A user is not satisfied if he does not have coverage or his communication request is rejected. This is a minimum requirement for the user to be satisfied. For the assessment of the algorithms for the cell outage compensation this will be important.

For the algorithm the performance criteria mentioned above will be used. The throughput, call blocking ratio and call dropping ratio will be the important assessment criteria for the network performance after the compensation.

To assess the performance of the cell outage compensation algorithms the network performance after the compensation has to be compared to the network performance after a cell outage and compensation activities in current networks. This should be done to assure that the performance of the algorithms is not overestimated. Since there is almost no cell outage compensation activity going on in the current networks the network performance after the compensation will most likely be compared to the network performance before the compensation, i.e., the network performance after the cell outage occurred.

2.3.5.2 Coverage

If the cell outage caused coverage holes, which is most likely, the coverage situation in the network will improve by changing antenna tilts and output power of surrounding cells during the compensation activities. That means parts of the uncovered area will be covered again after the cell outage compensation. Since it is one of the main objectives of the cell outage compensation to improve the coverage situation in the network in order to enable user service requests in the cell outage area, this metric will be a very important assessment criterion.

2.3.5.3 Capacity

The capacity in the area which is affected by the cell outage compensation activities, i.e., the area covered by the neighbouring cells of the cell in outage, will probably decrease due to increased cell output power, changed antenna tilts etc. However the capacity in the area which is uncovered due to the cell outage should increase during the cell outage compensation. Since the capacity may increase and decrease in different areas affected by the cell outage compensation activities it does not seem to make sense to use capacity as an assessment criterion. Due to the cell outage situation it will be impossible to provide satisfactory amount of capacity to all users. Moreover capacity as a metric does not provide additional information beyond what is provided by using performance.
2.3.5.4 Revenue
To assess the revenue of the SON algorithm the operated calls handled by the network after the compensation should be compared to the amount of operated calls handled by the network before the compensation. The otherwise missed revenue, i.e. the amount of calls from areas which are covered again after the compensation, should be larger than the missed revenue caused by the compensation activities by increasing output power and changing antenna tilts in neighbouring cells. It will also be important to assess if it makes sense from the revenue point of view to stop services that need more capacity like broadband data transfers.

2.3.5.5 CAPEX
Impact on hardware cost of adding cell outage compensation SON functionality is difficult to determine. There will most likely be additional costs for the installation of electric antenna tilting etc. which would largely shorten the reaction times of the cell outage compensation. There will be no positive effect on CAPEX due to cell outage compensation activities since the cells in outage will still have to be repaired.

2.3.5.6 OPEX
It has to be clarified if cell outage compensation activities are already going on in the current networks and if these activities can be automated. Tilting the antennas may not be possible without human activity if it can only be done manually. It depends on the actual situation and on the amount of human interaction in cell outage compensation activities if the OPEX is a useful assessment criterion or not.

2.3.5.7 Other metrics
Other useful metrics for this use case are:
- Stability
- Convergence time
- Complexity
- Robustness

2.3.6 Application of benchmarking to the cell outage compensation use case
Performance, coverage and revenue have all been found to be useful assessment criteria for this use case. Final assessment should be based on a combination of these three.

For the assessment of the algorithms it will be necessary to take the user and the operator point of view into account. From the user point of view the satisfied user criteria are the most important assessment criteria whereas the operators are interested in the end-user satisfaction and the revenue criteria. The cell outage situation is a temporary network situation which makes this use case special. It will be crucial for the assessment of the algorithms to meet the end-users and operators perspective.

The assessment criteria can be merged in groups. The first group shows the assessment criteria which are more important for this use case. The second group shows important assessment criteria. The other assessment criteria marked in Table 3 are less important.
- Primary criteria: call blocking ratio, call dropping ratio, outage, revenue, coverage
- Secondary criteria: fairness, throughput

Best benchmarking case: Operator that monitors network performance, and analyses the data to determine when a cell outage occurs and tries to compensate the cell outage timely.

Worst benchmarking case: Operator that only tries to repair cells timely, and does not monitor network performance.

2.3.7 Application of the metrics to the example use cases
A large number of metrics have been considered. Which of these metrics are useful will depend on the individual use cases. For most, and possibly all, of the use cases, a subset of the metrics will apply.

In Table 3, an overview is given of the application of the metrics for the example use cases. A tick indicates that the metric is interesting for that use case.
<table>
<thead>
<tr>
<th><strong>Performance (GoS/QoS)</strong></th>
<th>Intelligently selecting site locations</th>
<th>Packet scheduling parameter optimisation</th>
<th>Cell outage compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call blocking ratio</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Call dropping ratio</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Call success ratio</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Packet delay</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Transfer time</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Throughput</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Packet loss ratio</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean opinion score</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Fairness</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Outage</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Handover success rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum number of concurrent calls</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Maximum supportable traffic load</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum efficiency</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Revenue</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAPEX</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPEX</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other metrics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Convergence time</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Complexity</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Overhead</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Robustness</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 3: Application of the metrics to the example use cases.
3 Reference scenarios

3.1 Models that will be used in SOCRATES

In this section several models that will be used in the SOCRATES simulations to develop self organising algorithms are described. The models are grouped in three different categories, i.e., mobility models, traffic models and propagation models. It will be defined in the work packages 3 and 4 which models are going to be considered for the different use cases. If additional parameter settings or ranges are considered in the later simulations the model descriptions need to be updated accordingly.

Since the development and evaluation of the SON algorithms will be done in work package 3 and 4 which have not been started yet it might become necessary to add mobility, traffic or propagation models at a later stage of the SOCRATES project. Some of the models, especially the traffic models which were defined by NGMN [3], might be too complex for the needs of the SOCRATES project. The simplifications of these models will be done in work package 3 and 4 and updated in this section accordingly.

3.1.1 Mobility models

3.1.1.1 Random walk model

In the random walk model a mobility leg of a user with a given current location is determined by a randomly sampled direction of movement, a randomly sampled velocity and a randomly sampled motion time. The thus sampled leg is executed and once the motion time is over, the user waits at his reached location for a randomly sampled pause time, before sampling and executing the next leg. While the direction of movement is typically sampled from a uniform distribution Unif(0,2\pi), for the velocity, motion and pause time diverse continuous probability distributions may be applied, incl. deterministic distributions to enforce e.g., fixed uniform velocities or avoid pause times. In network scenarios with wraparound, it is important to continue a user's leg appropriately once it hits the boundary of the simulation area. The probability distributions for the different parameters are given in Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistical Characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pause time</td>
<td>Deterministic at 0 [s]</td>
</tr>
<tr>
<td>Direction of movement</td>
<td>Uniform (0, 2\pi)</td>
</tr>
<tr>
<td>Motion time</td>
<td>Exponential with average 30 [s]</td>
</tr>
<tr>
<td>Velocity</td>
<td>Uniform (0, 1.5) [m/s]</td>
</tr>
</tbody>
</table>

Table 4: Statistical characterisations for the different parameters.

3.1.1.2 Random waypoint model

In the random waypoint model a mobility leg of a user with a given current location is determined by a randomly selected destination and a randomly sampled velocity. The thus sampled leg is executed by moving the user to his selected destination in a straight line at the sampled velocity. Once the destination is reached, the user waits for a randomly sampled pause time, before sampling and executing the next leg. While the destination is typically (but need not be) uniformly sampled over the simulation area, for the velocity and pause time diverse continuous probability distributions may be applied, incl. deterministic distributions. Note that users cannot hit the boundary of the simulation area and hence a possibly applied wraparound feature is not needed for mobility reasons. The probability distributions for the different parameters are given in Table 5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistical Characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pause time</td>
<td>Deterministic at 0 [s]</td>
</tr>
<tr>
<td>Velocity</td>
<td>Uniform (0, 1.5) [m/s]</td>
</tr>
</tbody>
</table>

Table 5: Statistical characterisations for the different parameters.

3.1.1.3 Manhattan model

The Manhattan model is characterised by a (typically) regular grid of streets and avenues along which users move. A mobility leg of a user with a given current location is determined by a randomly sampled initial direction of movement, a randomly sampled velocity and a randomly sampled motion time. The thus sampled leg is executed, always randomly selecting a direction of movement at each reached
crossing, and once the motion time is over, the user waits at his reached location for a randomly sampled pause time, before sampling and executing the next leg. While the direction of movement is typically uniformly sampled (both at the generation of a new leg, and when reaching crossings during its execution), for the velocity, motion and pause time diverse continuous probability distributions may be applied, incl. deterministic distributions. In network scenarios with wraparound, it is important to continue a user's leg appropriately once it hits the boundary of the simulation area. The probability distributions for the different parameters are given in Table 6.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistical Characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pause time</td>
<td>Deterministic at 0 [s]</td>
</tr>
<tr>
<td>Direction of movement</td>
<td>Uniform</td>
</tr>
<tr>
<td>Motion time</td>
<td>Exponential with average 30 [s]</td>
</tr>
<tr>
<td>Velocity</td>
<td>Uniform (0, 1.5) [m/s]</td>
</tr>
</tbody>
</table>

Table 6: Statistical characterisations for the different parameters.

3.1.1.4 MOMENTUM mobility model for direction and speed estimation

In the MOMENTUM mobility model the direction and speed of users with a given current location (pixel based location) is estimated considering that users move in a pixel grid mobility scenario. The model gives the probability that a user crosses a side to a neighbouring pixel by including the effect of speed, pixel size, sample time and holding time.

The mobility model includes different mobility types in order to generate a realistic and diversified mobility scenario. The implicated mobility types are listed below:

- Static
- Pedestrian
- Street/vehicular
- Main Road/vehicular
- Highway/vehicular
- Highway traffic jam/vehicular
- Railway/vehicular

For each mobility type, probability distribution functions (PDFs) for speed and discrete direction of motion are given. Table 7 shows the triangular velocity distribution for the speed estimation with a specific average and variation for each mobility type.

<table>
<thead>
<tr>
<th>Mobility type</th>
<th>$V_{av}$ [m/s]</th>
<th>$V_{av}$ [km/h]</th>
<th>$\Delta$ [m/s]</th>
<th>$\Delta$ [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>1</td>
<td>3.6</td>
<td>1</td>
<td>3.6</td>
</tr>
<tr>
<td>Street/vehicular</td>
<td>10</td>
<td>36.0</td>
<td>10</td>
<td>36.0</td>
</tr>
<tr>
<td>Main Road/vehicular</td>
<td>15</td>
<td>54.0</td>
<td>15</td>
<td>54.0</td>
</tr>
<tr>
<td>Highway/vehicular</td>
<td>22.5</td>
<td>81.0</td>
<td>12.5</td>
<td>40.5</td>
</tr>
<tr>
<td>Highway traffic jam/vehicular</td>
<td>1</td>
<td>3.6</td>
<td>1</td>
<td>3.6</td>
</tr>
<tr>
<td>Railway/vehicular</td>
<td>22.5</td>
<td>81.0</td>
<td>22.5</td>
<td>81.0</td>
</tr>
</tbody>
</table>

Table 7: Mobility types average velocity and velocity variation.

Since user motion is limited to transitions between pixels in this model, only four possible directions for the mobile unit, forward (0°), back (180°), left (90°) and right (-90°) are considered possible, as illustrated in Figure 7. The direction probability values, for each mobility type, are given in Table 8. The different pixel grids, sample times and holding times that will be considered in SOCRATES are listed in Table 9.

---

4 The highway/vehicular model for Germany has a $V_{av}$ of $35 \frac{m}{s} (126 \frac{km}{h})$; the velocity variation remains unaltered.
### Figure 7: Possible pixel transition directions.

<table>
<thead>
<tr>
<th>Mobility type</th>
<th>0°</th>
<th>90°</th>
<th>-90°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>40</td>
<td>25</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Street/vehicular</td>
<td>50</td>
<td>25</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Main Road/vehicular</td>
<td>70</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Highway/vehicular</td>
<td>80</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Highway traffic jam/vehicular</td>
<td>80</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Railway/vehicular</td>
<td>80</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 8: Probability of changing direction values, for each mobility type.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel grids</td>
<td>5, 50 [m]</td>
</tr>
<tr>
<td>Sample time</td>
<td>1 [s]</td>
</tr>
<tr>
<td>Holding time</td>
<td>0 [s]</td>
</tr>
</tbody>
</table>

Table 9: Valid values for the different parameters.

The MOMENTUM mobility model can be used to generate movement in dynamic simulators. The level of detail is defined by the granularity of the raster, i.e., the pixel grid. The probability of changing position (or pixel) can be expressed by the generic direction vector (Table 8), the velocity (Table 7), the pixel size, the sample time and the holding time. More detailed information can be found in [12].

### 3.1.2 Traffic models

#### 3.1.2.1 Full queue model

Sometimes traffic modelling can be simplified by not modelling the exact arrival process and assuming full queue traffic. In this traffic model, all the users in the system always have data to send or to receive. So there is always a constant amount of data that needs to be transferred, in contrast to bursts of data that follow an arrival process.

#### 3.1.2.2 Best effort traffic: FTP

A FTP session is a sequence of file transfers separated by reading times, i.e., the time interval between the end of download of the previous file and the user request for the next file. The two parameters for a FTP session are:

- Size $S$ of a file
- Reading time $D$

A more detailed description of the FTP traffic model can be found in [3].

#### 3.1.2.3 Interactive traffic: web-browsing using HTTP

Web-pages consist of main objects and embedded objects like pictures and advertisements. The web-browser will load the main object first and parse for the embedded object afterwards. The parameters for web-browsing traffic are:

- The main size of an object $S_M$
• The size of an embedded object in a page $S_e$
• The number of embedded objects $N_D$
• Reading time $D$
• Parsing time for min page $T_p$

A more detailed description of the web-browsing traffic model can be found in [3].

3.1.2.4 Video streaming

Video data is transferred to the user in frames which arrive at a regular interval $T$. This interval is determined by the number of frames per second. The frames consist of a fixed number of slices and each slice is transmitted in a single packet. The video encoder introduces encoding delay intervals between the packets of a frame. The parameters for video streaming traffic are:

• Inter-arrival time between the beginning of each frame
• Number of packets (slices) in a frame
• Packet (slice) size
• Inter-arrival time between packets (slices) in a frame

A more detailed description of the video streaming traffic model can be found in [3].

3.1.2.5 VoIP

Voice over IP is a speech data traffic that is time critical because the user satisfaction depends on the ongoing data exchange that is necessary for the intelligibility of speech. Another criterion for user satisfaction is the time delay between the two users. A voice over IP user could be considered to be in outage if 98% radio interface tail latency of this user is greater than 50 ms. The parameters for VoIP traffic are:

• Codec
• Encoder frame length
• Voice activity factor (VAF)
• SID payload
• Protocol overhead with compressed header
• Total voice payload on air interface

A more detailed description of the voice over IP traffic model can be found in [3].

3.1.2.6 Gaming

Gaming data is transferred to the user in packets. The amount of data that has to be transferred depends on the game situation and will be different for up- and downlink which is taken into account in the statistical distributions for up- and downlink. Once the user started the game an initial packet arrives. A mobile network gaming user is considered to be in outage if the average packet delay is greater than 60 ms. The parameters for gaming traffic are:

• Initial packet arrival
• Packet arrival
• Packet size
• UDP header

A more detailed description of the gaming traffic model can be found in [3].

3.1.2.7 Traffic mixes

For traffic mixes the traffic models mentioned above, i.e., FTP, web-browsing, video streaming, voice over IP and gaming traffic, should be considered. Table 10 shows the traffic mix that will be considered in the SOCRATES project.
<table>
<thead>
<tr>
<th>Application</th>
<th>Traffic Category</th>
<th>Percentage of Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP</td>
<td>Best effort</td>
<td>10 %</td>
</tr>
<tr>
<td>Web-browsing</td>
<td>Interactive</td>
<td>20 %</td>
</tr>
<tr>
<td>Video streaming</td>
<td>Streaming</td>
<td>20 %</td>
</tr>
<tr>
<td>VoIP</td>
<td>Real-time</td>
<td>30 %</td>
</tr>
<tr>
<td>Gaming</td>
<td>Interactive real-time</td>
<td>20 %</td>
</tr>
</tbody>
</table>

Table 10: User traffic mix.

A more detailed description of the traffic mixes can be found in [3].

3.1.3 Propagation models

3.1.3.1 Okumura-Hata model

The Okumura Hata model is one of the most widely used propagation models. The model is based on measurements made by Y. Okumura formulated in a mathematical model by M. Hata. The method is valid for cells with a cell radius from 1 to 20 kilometres, base station heights from 30 to 200 meters, mobile station heights from 1 to 10 meters and for frequencies between 150-1000 MHz [13].

In urban areas, the Okumura-Hata model gives the following expression for the path loss [dB]:

$$ L = 69.55 + 26.16 \log f_c - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log r - a(h_m) $$

where

- $f_c$ is the carrier frequency [MHz],
- $h_b$ is the height of the base station antenna [m],
- $r$ is the distance between the base station antenna and the mobile station antenna [km], and
- $h_m$ is the height of the mobile station antenna [m].

The expression for $a(h_m)$ depends on the carrier frequency and the type of city. For carrier frequencies above 300 MHz, where LTE will be deployed, the following expression is valid for propagation in large cities:

$$ a(h_m) = 3.2 \left( \log (1.75 h_m) \right)^2 - 4.97 $$

For propagation in medium to small cities the expression is

$$ a(h_m) = (1.1 \log f_c - 0.7) h_m - (1.56 \log f_c - 0.8) $$

for all valid frequencies.

In suburban areas the path loss is instead given by the following expression:

$$ L = 69.55 + 26.16 \log f_c - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log r - B $$

where $B$ is given by

$$ B = 2 \left( \log \left( \frac{f_c}{28} \right) \right)^2 + 5.4 $$

Finally, in open areas the expression is given by

$$ L = 69.55 + 26.16 \log f_c - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log r - C $$

where

$$ C = 4.78 \left( \log (f_c) \right)^2 - 18.33 \log f_c + 40.94 $$

Table 11 shows the validity ranges for the Okumura-Hata model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequencies</th>
<th>Cell Radius</th>
<th>Base station height</th>
<th>Mobile station height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Okumura-Hata</td>
<td>150 - 1000 MHz</td>
<td>1 - 20 km</td>
<td>30 - 200 m</td>
<td>1 - 10 m</td>
</tr>
</tbody>
</table>

Table 11: Validity Ranges for the Okumura-Hata model.
3.1.3.2 COST 231-Hata model

The European body COST 231 has adjusted the Okumura-Hata model to be valid for higher frequencies. The result is the COST 231-Hata model, which is valid for frequencies between 1500 and 2000 MHz. Just like the Okumura-Hata model, the COST 231-Hata model is valid for cells with a cell radius of 1-20 kilometres, base station heights of 30-200 meters and mobile station heights of 1-10 meters [14].

The COST 231-Hata model gives the following expression for the path loss

\[ L = 46.3 + 33.9 \log f_c - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log r - a(h_m) + G \]  

where \( a(h_m) \) is taken from the Okumura-Hata model presented above, and

\[ G = \begin{cases} 
0 \text{ dB for medium-sized cities and suburban centers with medium tree density} \\
3 \text{ dB for metropolitan centers} 
\end{cases} \]

Table 12 shows the validity ranges for the COST 231-Hata model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequencies</th>
<th>Cell Radius</th>
<th>Base station height</th>
<th>Mobile station height</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST 231-Hata</td>
<td>1500 - 2000 MHz</td>
<td>1 - 20 km</td>
<td>30 - 200 m</td>
<td>1 - 10 m</td>
</tr>
</tbody>
</table>

Table 12: Validity ranges for the COST 231-Hata model.

3.1.3.3 Walfisch-Ikegami model (COST 231)

COST 231 also proposed a combination of the Walfish and Ikegami models to estimate the path loss in urban areas. The model is valid for frequencies from 800 to 2000 MHz, base station heights from 4 to 50 meters, mobile station heights from 1 to 3 meters and cell radius from 0.02 to 5 kilometres [14]. The model considers data describing the character of the studied area, such as:

- heights of buildings \( h_r \) [m]
- widths of roads \( w \) [m]
- building separation \( b \) [m], and
- road orientation with respect to the direct radio path \( \varphi \) [°]

See Figure 8 and Figure 9 for illustration.

\[ h_b \quad h_m \quad h_r \quad w \quad b \]

Figure 8: Illustration of the parameters \( h_b \) – height of base station, \( h_m \) – height of mobile station, \( h_r \) – heights of buildings, \( w \) – widths of roads, and \( b \) – building separation.
In case of line-of-sight, the path loss is given by

$$ L = 42.6 + 26 \log r + 20 \log f_c \tag{9} $$

In the non-line-of-sight case, the path loss is given by

$$ L = \begin{cases} 
L_0 + L_{rts} + L_{msd} & \text{for } L_{rts} + L_{msd} > 0 \\
L_0 & \text{for } L_{rts} + L_{msd} \leq 0 
\end{cases} \tag{10} $$

where

- $L_0$ is the free space loss,
- $L_{rts}$ is the roof-top-to-street diffraction and scatter loss,
- $L_{msd}$ is the multiple screen diffraction loss, and

the free space loss is given by

$$ L_0 = 32.4 + 20 \log (r) + 20 \log (f_c) \tag{11} $$

The roof-top-to-street diffraction and scatter loss describes the coupling of the radio wave along the multiple-screen path into the street where the mobile station is located. It is given by:

$$ L_{rts} = -16.9 - 10 \log (r) + 10 \log f_c + 20 \log \Delta h_m + L_{Ori} \tag{12} $$

where

$$ L_{Ori} = \begin{cases} 
-10 + 0.354 \varphi & \text{for } 0^\circ \leq \varphi < 35^\circ \\
2.5 + 0.075(\varphi - 35) & \text{for } 35^\circ \leq \varphi < 55^\circ \\
4.0 - 0.114(\varphi - 55) & \text{for } 55^\circ \leq \varphi < 90^\circ 
\end{cases} \tag{13} $$

$$ \Delta h_m = h_r - h_m \tag{14} $$

$$ \Delta h_b = h_b - h_r \tag{15} $$

The multiple screen diffraction loss is determined by modelling the heights of buildings and their spatial separations along the direct radio path as absorbing screens.

$$ L_{msd} = L_{bsh} + k_a + k_d \log r + k_f \log f_c - 9 \log h \tag{16} $$

where
In cases where the structure of roads and buildings is unknown, the following values are recommended to use as default:

\[ h_r = 3 \cdot \text{(number of floors)} + \begin{cases} 
3 & \text{for pitched roofs} \\
0 & \text{for flat roofs} 
\end{cases} \]  

(21)

Parameters:
\[ b = 20 \ldots 50 \text{ [m]} \]
\[ w = b/2 \text{ [m]} \]
\[ \phi = 90^\circ \]

Table 13 shows the validity ranges for the Walfish-Ikegami model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequencies</th>
<th>Cell Radius</th>
<th>Base station height</th>
<th>Mobile station height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walfish - Ikegami</td>
<td>800 - 2000 MHz</td>
<td>0.02 - 5 km</td>
<td>4 - 50 m</td>
<td>1 - 3 m</td>
</tr>
</tbody>
</table>

Table 13: Validity ranges for the Walfisch-Ikegami model.

3.1.3.4 Choosing the propagation model

The choice of propagation model depends on the area studied and the purpose of the study. For cells with a radius smaller than 5 km the COST 231 Walfish-Ikegami model captures variations due to buildings in urban areas. The Okumura-Hata and the COST 231 - Hata models are suitable for larger cells. LTE can be deployed in various frequency bands. The appropriate propagation model for the frequency band under consideration should be used. The COST 231 - Hata model is the model most suited for path loss estimation in macro cells with a cell radius larger than 5 km. The Okumura-Hata model can however be used to study the LTE bands around 800 MHz.

3.1.3.5 Fading models

In general, fading models are used for describing the change of the signal strength over time (e.g., due to moving obstacles) and space (e.g., due to movement of the mobile station) due to multi-path or shadowing effects. Figure 10 illustrates all effects of signal propagation in different environments, and
Figure 11 shows a qualitative example of the received signal strength including correlated shadowing and fast fading.

![Diagram of mobile multipath scenario](image)

**Figure 10:** Example of a multipath scenario in mobile environments including shadowing, diffraction, reflection and scattering.

**Figure 11:** Qualitative example of receiver signal strength variation considering fast and slow fading over time or space

### Fast fading

Fast fading is caused by multipath propagation. Several same signals are arriving at the receiver on different ways due to reflection and scattering of the original one. The resulting signal is the sum of all received signals considering the appropriate delay. In order to model fast fading, two different cases are considered: non-line-of-sight (Rayleigh fading) and line-of-sight (Rician fading).

**Rayleigh fading:** In the non-line-of-sight (NLOS) case no direct path exists. The imaginary and real parts of the resulting signal are Gaussian distributed. The phase is uniformly distribution in $[0, 2\pi]$. The power is exponentially distributed. The amplitude of the resulting signal is Rayleigh distributed. Therefore, the fading can be described with the Rayleigh distribution specified in Equation 22 with $r$ being the absolute value of the received signal.

$$p_r(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, r \geq 0 \quad (22)$$

**Rician Fading:** In a line-of-sight (LOS) case, the resulting complex Gaussian has a non-zero mean due to a dominating direct path $s$. All other signals combined to $r$ follow a Rayleigh distribution. Equation 23
shows the probability density function of the resulting signal with $I_0$ being the modified Bessel function of order zero.

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{(r^2+\sigma^2)}{2}} I_0\left(\frac{rs}{\sigma^2}\right)$$  \hspace{1cm} (23)$$

The Rice factor $k = \frac{s^2}{2\sigma^2}$ defines the relation between the powers of direct path to all other signals. If $k$ is large, the direct path dominates. For a $k \to -\infty$ no dominating path exists, leading to a Rayleigh distribution.

**Slow fading**

Slow fading is caused by shadowing of buildings, hills, and other obstacles, like moving cars. Therefore, the signal strength varies in the scale of the sizes of these obstacles.

The variation of slow fading $L_{SF}$ [dB] can be modelled using a log-normal distribution and will be added to the mean propagation loss described in the paragraphs above [15]. Equation 24 describes the probability density function of the shadowing variation in [dB] with the location variability $\sigma_{SF}$.

$$p(L_{SF}) = \frac{1}{\sigma_{SF}\sqrt{2\pi}} e^{-\frac{L_{SF}^2}{2\sigma_{SF}^2}}$$  \hspace{1cm} (24)$$

The location variability $\sigma_{SF}$ is dependent on the used transmitting frequency with the tendency to increase with higher frequencies. Also the local clutter is influencing the variability. Suburban areas tend to have larger values due to larger variations in the environment, whereas in urban areas lower variations occur. In Equation 25 the calculation of $\sigma_{SF}$ for macro cells depending on the transmitting frequency $f$ [MHz] and the local clutter class ($A_{urban} = 5.2$ and $A_{suburban} = 6.6$ [dB], respectively) is specified.

$$\sigma_{SF} = 0.65(\log_{10} f)^2 - 1.3(\log_{10} f) + A$$  \hspace{1cm} (25)$$

**Correlated slow fading**

For the shadowing of signals correlation can be observed for movement of the mobile station (serial correlation, single-site case) or between signals from different base stations (site-to-site correlation). As depicted in Figure 12 two mobile stations (MS1 and MS2) are separated by distance $r_m$ and receive signals from two different base stations (BS1 and BS2). The shadowing paths ($S_{11}, S_{12}, S_{21},$ and $S_{22}$) are assumed to be log-normal distributed (zero-mean Gaussian when expressed in [dB]). It is assumed that they are not independent of each other.

![Figure 12: Shadowing correlation (based on [15]).](image)
**Single-Site Case:** Correlation between two mobile locations if the signal is received from one base station (S11 and S12, S21 and S22). The mobile station has moved with a distance \( r_m \). The correlation between locations of the mobile station can be expressed by the empirical normalized correlation function (Equation 26).

\[
R(r_m) = e^{-r_m/r_c}
\]

The serial correlation distance (shadowing correlation distance) \( r_c \) can be determined by taking the distance of the normalized autocorrelation function to fall to \( e^{-1} \approx 0.37 \). Figure 13 and Figure 14 depict the comparison of measurements (dotted line) and equation (solid line) for suburban and urban scenarios [16].

![Figure 13: Normalized autocorrelation function for suburban areas [16]. \( \sigma = 7.5dB, R(r_m = 100m) = 0.82 \)](image)

![Figure 14: Normalized autocorrelation function for urban areas [16]. \( \sigma = 4.3dB, R(r_m = 10m) = 0.3 \)](image)

Figure 15 shows the general process to implement correlated shadowing using a sample rate \( T \), the velocity of the mobile \( v \) [m/s].

![Figure 15: Method for generating correlated shadowing process (based on [15]).](image)

**Site-to-Site Case:** Correlation between two base stations for a single mobile station location (S11 and S21 or S12 and S22). Figure 16 shows a model for shadowing cross correlation with distances from base station to mobile station (\( r_1 \) and \( r_2 \)) and angle \( \alpha \) between the paths.
Carrier-to-Interference ratio CIR [dB] is added to the result of the Singe-Site Case. It is assumed that this interference is modelled by a Gaussian random variable using the parameters specified in (27), with \( n \) being the path loss exponent.

\[
\mu_R = E[CIR] = 10n \log \left( \frac{r_2}{r_1} \right) \quad \text{and} \quad \sigma^2 = E[CIR^2] - (E[CIR^2])^2 = \sigma_1^2 + \sigma_2^2 - 2\rho_1\sigma_1\sigma_2
\]  

(27)

The cross-correlation can be calculated by (28) with \( \gamma \) being an exponent to consider variation of \( \alpha \) due to different terrain and clutter sizes.

\[
\rho_\alpha = \begin{cases} 
\sqrt{\frac{r_1}{r_2}} & \text{for } 0 \leq \alpha < \alpha_T \\
\left( \frac{\alpha_T}{\alpha} \right)^{\sqrt{\frac{r_1}{r_2}}} & \text{for } \alpha_T \leq \alpha \leq \pi
\end{cases}
\]  

(28)

More detailed information can be found in [16, 17].

### 3.1.3.6 Multi-path model for MIMO

Spatial channel model (SCM) has been developed by combined 3GPP-3GPP2 ad-hoc group. The scope of the group was to specify and develop parameters and methods associated with the spatial channel modelling that were common to the needs of the 3GPP and 3GPP2 organisations. The output of work has been detailed in [18].

The SCM provides a single unified spatio-temporal model for several environments such as suburban macro cell, urban macro-cell, and urban micro cell. It represents the frequency-selective MIMO channel as a superposition of clustered constituents, which are specified in terms of powers, angles of arrival and departure, and time of arrival. Parameters are specified stochastically and are correlated with each other. The SCM provides a good balance between realistic, experimentally verified, spatial and temporal channel models and modelling complexity.

In WINNER project [19] SCM has been extended with additional features to support 5GHz centre frequency, wider frequency range and more propagation scenarios. The recent implementation is version 0.61 from November 2007.

WINNER MIMO radio channel model enables system level simulations and testing. This means that multiple links are to be simulated (evolved) simultaneously. System level simulation may include multiple base stations, multiple relay stations, and multiple mobile terminals as in Figure 17. Link level simulation is done for one link, which is shown by blue dashed ellipse. The short blue lines represent channel segments where large scale parameters are fixed. System level simulation consists of multiple links. Both link level and system level simulations can be done by modeling multiple segments or by only one (CDL model) [20].
A single link model is shown in Figure 18. The parameters used in the models are also shown in the figure. Each circle with several dots represents scattering region causing one cluster. The number of clusters varies from scenario to another.

The received signal at the Mobile Station (MS) consists of $N$ time-delayed multipath replicas of the transmitted signal. These $N$ paths are defined by powers and delays and are chosen randomly according to the channel generation procedure. Each path consists of $M$ subpaths. Detailed reference can be found in [18].

Current implementation supports several different scenarios in frequency range of 2-6 GHz:

- indoor small office / residential
- large indoor hall
- indoor to outdoor
- typical urban (macro and micro-cell)
- suburban
• bad urban
• rural
• and more

For all scenarios line of sight (LOS) and/or non line of sight (NLOS) modes as well as different velocities are supported. All large scale parameters and angular parameters are specified according to the scenario.

3.1.3.7 Model used by Vodafone to calculate coverage maps

For studies and simulations where realistic scenarios are required, Vodafone will use an advanced propagation model called PACE. Close to the base station, this model uses a 3D ray-tracing algorithm. Further away from the base station, 2D predictions are used.

The PACE model is used for network planning by Vodafone UK, Vodafone Germany, and a number of other Vodafone operators. It is integrated with planning tools, so can be used to predict coverage in realistic network environments (see Figure 19).

![Figure 19: Example of a coverage prediction using PACE.](image)

3.2 Network topologies

3.2.1 Hexagonal network topology

A hexagonal cellular scenario is a simplified structure with equal assumptions for each site, having e.g., same antenna height, sectorisation and transmitting power. Each site has the same distance to its direct neighbours. Thus, the best server structure leads to a hexagonal structure for each of the sectors. Figure 20 shows the basic structure of hexagonal sectors for one site. Using hexagonal structure, simplified scenarios can be developed for fast calculations. Nevertheless, due to simplified structure, limitations of the accuracy of the simulation results will occur.
Figure 20: Basic structure of hexagonal cells.

The main parameters of the hexagonal structure are summarised in Table 14. More parameters can be defined for system-level simulation assumption based on [21]. These parameters will be selected and specified in work package 3 and work package 4 depending on each use case separately.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Explanation/assumption</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular layout</td>
<td>Hexagonal grid, 3-sector sites</td>
<td>See Figure 20</td>
</tr>
<tr>
<td>Site to site distance</td>
<td>500m, 1000m or 1732m</td>
<td></td>
</tr>
<tr>
<td>Number of sites within the scenario</td>
<td>19 or 48</td>
<td>See Figure 21</td>
</tr>
</tbody>
</table>

Table 14: Parameters of cellular network structure.

Figure 21: Hexagonal network topology with 19 and 48 cells.

3.2.2 Realistic network topologies

3.2.2.1 Berlin

The first reference scenario that will be used in the SOCRATES project is a scenario in the city centre of Berlin. The coordinates for this scenario are given in Table 15.

<table>
<thead>
<tr>
<th>Reference Scenario</th>
<th>x-boundaries</th>
<th>y-boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlin</td>
<td>x_min: 3789000 GK</td>
<td>y_min: 5824000 GK</td>
</tr>
<tr>
<td></td>
<td>x_max: 3802000 GK</td>
<td>y_max: 5837000 GK</td>
</tr>
</tbody>
</table>

Table 15: Boundaries of the Berlin reference scenario (Gauß-Krüger (GK4) coordinate system).
The Berlin-Scenario includes urban and dense-urban areas as well as some hot-spot areas like the central station or the Berlin-Tegel airport. The terrain height varies by about 20 m within the whole scenario, which can therefore be described as a flat area scenario. It also includes a planned LTE testing area located at the Ernst-Reuter-Platz.

A more detailed description of the reference scenario including propagation maps will be added later since the necessary data for the description is not available at the moment.

### 3.2.2.2 Braunschweig

The second reference scenario that will be used in the SOCRATES project is a scenario around the city of Braunschweig. The coordinates for this scenario are given in Table 16.

<table>
<thead>
<tr>
<th>Reference Scenario</th>
<th>x-boundaries</th>
<th>y-boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braunschweig</td>
<td>x_min: 4369000 GK</td>
<td>y_min: 5735000 GK</td>
</tr>
<tr>
<td></td>
<td>x_max: 4409000 GK</td>
<td>y_max: 5805000 GK</td>
</tr>
</tbody>
</table>

Table 16: Boundaries of the Braunschweig reference scenario (Gauß-Krüger (GK4) coordinate system).

The Braunschweig-Scenario is a larger scenario that includes urban and sub-urban areas like the medium size cities Braunschweig and Peine, and rural areas in between them. In contradiction to the Berlin-Scenario the terrain height varies about 700 m due to parts of the Harz mountain range located in the scenario.

A more detailed description of the reference scenario including propagation maps will be added later since the necessary data for the description is not available at the moment.

### 3.2.2.3 Required scenario data

The detailed scenario data that is needed for the reference scenarios are listed below. They are separated into five parts: cell data, measurement data, spatial data, path loss data and special cell data for site identification in drive tests.

1) **Cell Data (Site Database)**
   - Type (Cell/Repeater)
   - Indoor/Outdoor
   - Sector information (Site ID, azimuth, …)
   - Tilt (electric/mechanic)
   - Height
   - Location
   - Antenna-Diagram
   - Output-Power
   - Minimum required received Power (threshold to log on to BS)
   - Hierarchy information (TRX→BTS→BS→MSC, LAC/RAC/URA)
   - Handover parameters (handover thresholds, …)
   - Feeder losses
   - MHA/TMA

2) **Measurement Data**
   - Location Area Updates / Tracking Area Updates (Mobility Patterns)
   - Ingoing and outgoing traffic (BHCA, total traffic, MTC, MOC, …)
   - Handover counters (statistical distribution)
• Handover reasons (Power, Quality, …)
• Traffic in relation to the distance from the site

3) Spatial Data
• Building-Data (Vector-Data)
• Traffic routes (streets, rails, rivers, …) (Vector-Data)
• Land-use classes (Pixel-Maps)
• Ground level elevation (Pixel-Maps)
• Population (Pixel-Maps)
• Traffic Maps (Pixel-Maps)

4) Pathloss Data
• Data from previous Drive Tests (if available)
• Pathloss Predictions

5) Special Cell Data for site identification in drive tests
• Allocated frequencies (GSM)
• BSIC (GSM)
• Number of carriers/ID’s (UMTS)
• Scrambling Codes (UMTS)
• Capacity (number of TRX/TS/Codes(UMTS))
• HSDPA/GPRS parameters
• Neighbour lists

3.2.2.4 Drive test measurements
Since no LTE network is available so far the drive tests will be done with 2G and 3G networks. For every reference scenario smaller drive test areas will be defined at a later time. The measurements, which will only be taken for these smaller areas, will be very detailed, i.e. even in rural drive test areas almost every street will be taken into account. This detailed information will help to improve the development of the algorithms. Later on the algorithms can be evaluated using the complete reference scenarios. Figure 22 shows an exemplary overview of a virtual reference scenario. It shows the positions of the base stations in the complete (blue) area and in some smaller (green) parts, which represent the drive test areas. The drive tests should be performed at the same time the area information is valid for.
Figure 22: Exemplary illustration of a reference scenario.
4 Concluding remarks

In this document, assessment criteria have been defined that will be applied when evaluating the gains of self-organisation solutions. Also the reference scenarios that will be used for simulation of these solutions, have been introduced.

In the ‘Assessment Criteria’ chapter (Chapter 2), several performance, coverage and capacity metrics have been introduced. Then models for determining cost related metrics, i.e., revenue, CAPEX and OPEX, have been proposed. Also metrics based on the technical requirements defined in the SOCRATES deliverable D2.2 have been considered. A benchmarking approach has been outlined that serves two purposes: (i) allow to make a mutual comparison of different self-organisation methods developed for a given use case, based on the defined metrics, and (ii) allow to assess the gains that can be achieved using self-organising networks by comparison of the obtained results, based on the defined metrics, with results obtained in the case with manual network operation. Then the metrics and benchmarking approach have been applied to three example use cases. By doing so, it has been shown that the defined assessment criteria will be applicable for the future work of the SOCRATES project.

In the ‘Reference Scenarios’ chapter (Chapter 3), the different mobility, traffic and propagation models that will be used in the future SOCRATES simulation studies in WP3 and WP4 have been considered. These include both simple as well as more advanced models. Then the network topologies have been presented. The hexagonal network topology will be used for standard simulations, whereas the realistic network topologies will be used for more detailed simulations. The scenario data that is needed for the realistic network topologies has been listed, together with the special cell data for site identification that will be obtained by performing drive tests.

The assessment criteria and reference scenarios for self-organising networks presented in this deliverable, together with the use cases and requirements presented in the previous SOCRATES deliverables D2.1 and D2.2, form the basis of the framework for the development of self-organisation methods that will be developed in deliverable D2.4. The actual development of the algorithms based on this framework will then be the subject of WP3 and WP4.
5 References