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Cell Outage Management in LTE Networks

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Abstract — **Cell outage management is a functionality aiming to automatically detect and mitigate outages that occur in radio networks due to unexpected failures. We envisage that future radio networks autonomously detect an outage based on measurements, from e.g., user equipment and base stations, and alter the configuration of surrounding radio base stations in order to compensate for the outage-induced coverage and service quality degradations and satisfy the operator-specified performance requirements as much as possible. In this paper we present a framework for cell outage management and outline the key components necessary to detect and compensate outages as well as to develop and evaluate the required algorithms.**

I. Introduction

The standardisation body 3rd Generation Partnership Project (3GPP) has finalised the first release (Release 8) of the UMTS successor named Evolved UTRAN (E-UTRAN), commonly known as Long Term Evolution (LTE). In parallel with the LTE development, the Next Generation Mobile Network (NGMN) association of operators brings forward requirements on management simplicity and cost efficiency [1][2][3]. A promising approach for achieving these requirements is the introduction of self-organisation functionalities into the E-UTRAN [4]. One aspect that benefits from self-organisation is cell outage management (COM), which can be divided into cell outage detection (COD) and cell outage compensation (COC).

There are multiple causes for a cell outage, e.g., hardware and software failures (radio board failure, channel processing implementation error, etc.), external failures such as power supply or network connectivity failures, or even erroneous configuration. While some cell outage cases are *detected* by operations & management system (O&M) through performance counters and/or alarms, others may not be detected for hours or even days. It is often through relatively long term performance analyses and/or subscriber complaints that these outages are detected. Currently, discovery and identification of some errors involves considerable manual analysis and may require unplanned site visits, which makes cell outage detection rather costly. It is the task of the automated cell outage detection function to timely trigger appropriate *compensation* methods, in order to alleviate the degraded performance due to the resulting coverage gap and loss in throughput by appropriately adjusting radio parameters in surrounding sites. Moreover, if required, an immediate alarm should be raised indicating the occurrence and cause of an outage, in order to allow swift manual *repair*.

Cell outage detection has previously been studied and reported in literature, e.g., [5][6][7]. In [5], historic information is used in a Bayesian analysis to derive the probability of a cause (fault that initiates the problem) given the symptoms (manifestations of the causes). Knowledge of radio network experts is needed as well as databases from a real network in order to diagnose the problems in the network. In [7], a cell outage detection algorithm, which is based on the neighbour cell list reporting of mobile terminals is presented and evaluated. The detection algorithms acts on changes in neighbour reporting patterns, e.g., if a cell is no longer reported for a certain period of time then the cell is likely to be in outage. In comparison with previous approaches we consider a broader perspective and consider not only detection but also cell outage compensation. Off-line optimisation of coverage and capacity has been reported in e.g., [8][9][10][11] and [12]. Coverage and capacity are optimised by appropriately tuning, e.g., the pilot power, antenna tilt and azimuth. Although such *off-line* optimisation methods may provide useful suggestions, for cell outage compensation it is important to develop methods that adjust involved parameters *on-line* and in *real-time* in order to timely respond to the outage. Further, some approaches consider single-objective optimisation (e.g., capacity), whereas we believe that multiple objectives (e.g., combination of coverage and quality) need to be considered. As such, in contrast to previous work, we intend to develop methods for real-time and multi-objective control and optimisation of LTE networks.

In this paper we present a framework for COM and describe the needed functionalities and their corresponding interrelations, as described in Section II. Further, we address a number of key aspects that play a role in the development of cell outage management algorithms. This includes a definition of operator policies regarding the trade-off between various performance objectives (Section III), an overview of potentially useful measurements (Section IV), and a set of appropriate control parameters (Section V). For development and evaluation of detection and compensation algorithms we propose a set of suitable scenarios (Sections VI), and present our assessment methodology and associated criteria (Section VII). The paper is concluded in Section VIII, where we also present our future work.

II. Overview of Cell Outage Management

The goal of cell outage management is to minimise the network performance degradation when a cell is in outage through quick detection and compensation measures. The latter is done by automatic adjustment of network parameters in surrounding cells in order to meet the operator's performance requirements based on coverage and other quality indicators, e.g., throughput, to the largest possible extent. Cell outage compensation algorithms may alter, e.g, the antenna tilt and the cell transmit power, in order to cover the outage area.

Altering the radio parameters of the neighbouring cells means that some of the user equipments (UEs) served by those cells may be affected. This should be taken into account and an appropriate balance between the capacity/coverage offered to the outage area and the unavoidable performance degradation experienced in the surrounding cells, should be achieved. This balance is indicated by means of an operator policy that governs the actions taken by the cell outage compensation function (see also Section III).

Figure 1 shows the components and workflow of cell outage management. Various measurements are gathered from the UEs and the base stations (called eNodeBs in LTE). The measurements are then fed into the cell outage detection function, which decides whether at the current time an outage has occurred and triggers the cell outage compensation function to take appropriate actions. In the example given in Figure 1, the base station in the center is in outage, resulting in a coverage hole. The neighbouring cells have increased their coverage in order to alleviate the degradation in coverage and quality.

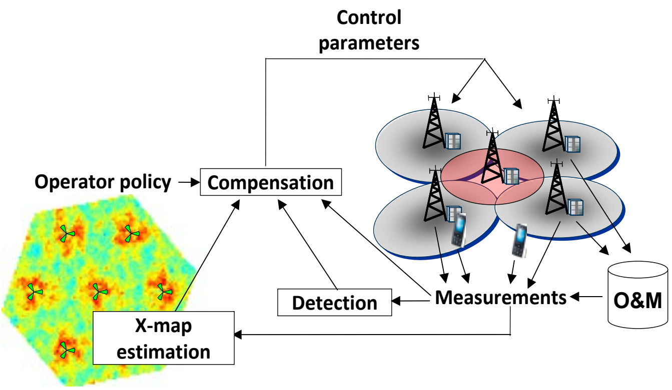

Figure 1 Overview of the cell outage management components. The center site is in outage. Red area indicates the previous coverage of the outage cell.

Cell outage compensation is typically characterised by an iterative process of radio parameter adjustment and evaluation of the performance impact. In this process there is a clear need to estimate the performance in the vicinity of the outage area. This is useful in order to determine to what degree the compensation actions are successful in terms of satisfying the given operator policy during an outage. This can be provided by the so-called *X-map estimation* function, which continuously monitors the network and by possibly using other sources of information such as propagation prediction data, estimates the spatial characteristics of the network, e.g., coverage and quality. Essentially, an X-map is a geographic map with overlay performance information.

III. Operator Policy

The configuration changes for compensating a cell outage influence the network performance. For the network performance every operator has its own policy, which may range from just providing coverage up to guaranteeing high quality in the network. This policy may even be different for various cells in the network and may vary for cell outage situations and normal operation situations. Furthermore, the policies may be declared differently depending on the time/day of the week. Below we propose a general framework for defining an operator policy, taking into account the above mentioned aspects.

In a cell outage situation an operator may still target the ideal goal of achieving the best possible coverage, providing the highest accessibility, and delivering the best possible quality in the cell outage area and all surrounding cells. In most cases, not all these goals can be fulfilled at the same time. As a consequence the targets have to be weighted and/or ranked in order to provide quantitative input to an optimisation procedure. Depending on the operator's policy the optimisation goal itself may vary, i.e., the weighting and the ranking of the targets may differ. Hence, the policy definition should be modular/flexible enough to capture different operator strategies, e.g., coverage-oriented strategy vs. capacity-oriented strategy.

When defining the cost function for optimisation and assessment purposes, it is important to include all cells that are affected in one way or another by the COC algorithm. In this light, three groups of cells can be distinguished (see Figure 2): (1) the cell in outage, (2) cells whose parameters may be adapted by the COC algorithm, and (3) those surrounding cells whose parameters are not adapted, but whose performance may be affected by the COC actions.

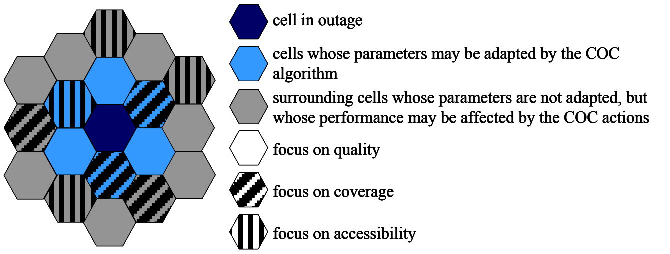

Figure 2 Cells that are considered when defining a cost function.

The optimisation goals considered in the cost function may vary for different cells. For example, in cells covering large areas the coverage should be kept high, whereas in high-capacity cells located in the same region the focus will be more on accessibility and/or quality. As a consequence, the optimisation goals have to be defined on a per-cell basis.

Furthermore, some cells might be more important for the network operator then other cells due to, e.g., the number of customers or generated traffic by the customers in these cells. As such, in addition to the different optimisation goals, cells may have different importance or priorities. The cost function has therefore to take into account all optimisation goals per cell, i.e., coverage, accessibility, and quality, as well as the corresponding importance. Since it is not possible to derive the coverage, accessibility, and quality for the cell in outage, the cost function may consider only the accessibility and quality of the surrounding cells and the coverage of the whole sub-network.

IV. Measurements

The continuous collection of measurements and analysis of radio parameters, counters, KPIs, statistics, alarms, and timers, are an indispensable precondition for the detection and compensation of a cell outage. In the following these various information sources are described as measurements. These measurements may be obtained from various sources (refer to [13] for an overview of the LTE architecture): (1a) the eNodeB which is affected by the cell outage (as far as there are still measurements available), (1b) the neighbouring eNodeBs, (2) UEs, and (3) O&M system and access gateway(s). Note that it is to be further investigated to which extent these measurements are suitable for use in COM functions. Some major examples are given below:

A. Measurements from eNodeBs:

- Cell load, e.g. the load can be used to indicate the degree of traffic that is carried during outage.
- Radio Link Failure (RLF) counter, e.g. a sudden increase in number of RLFs may indicate a cell outage.
- Handover failure rate, e.g., high handover failure rate may indicate a cell outage.
- Inter-cell interference, e.g., a sudden change of the interference level may be used to indicate outages. Further, interference measurements are required to detect incorrect settings of tilt or cell power during compensation.
- Blocked / dropped calls, e.g., high number of dropped calls may indicate a coverage hole.
- Cell throughput and per-UE throughput.

B. Measurements from UE

- Reference Signal Received Power (RSRP) measurements taken by the UE of the serving and surrounding cells. For example, if a neighbouring cell is no longer reported then this may be an indication of an outage.
- Failure reports are generated by the UE after connection or handover failures and sent to eNodeB for cause analysis. Note, failure reports are not standardised yet.

C. Measurements from O&M

KPIs and statistics are continuously calculated at the O&M system. Some of these measurements can be used for the purpose of outage detection and to validate performance during and after outage compensation. Alarms appearing at the O&M system may also be used for outage detection.

For outage detection, taking all the described measurements into account, a dedicated algorithm is required that combines the measurements and uses an appropriate decision logic to determine whether an outage has occurred or not.

Regarding COC, it is clear that the goals presented in Section III need to be measurable. Accessibility and quality can be assessed by measurements such as call block ratio and per-UE throughput. The coverage presents by far greater challenges. One idea that we are currently pursuing is to estimate coverage using UE measurement reports. Estimates of the geographic coordinates of the mobile position may be assigned to the obtained measurement reports in order to derive a map which relates geo-reference data to performance related metrics, e.g., path loss (cf. also Figure 1). We are intending to investigate to which degree coverage can be estimated based on UE reports (utilising position information) as well as what accuracy is needed as input to the COC algorithms.

V. Control parameters

All radio parameters that have an impact on coverage and capacity are relevant from a cell outage compensation point of view. This includes transmit power and antenna parameters.

The power allocated to the physical channels dictates the cell size. On the one hand, by increasing the physical channel power the coverage area of a cell can be increased (in order to compensate for outage). On the other hand, by lowering the cell power the cell area is reduced and as a consequence load and interference caused by the cell can also be reduced.

Further, modern antenna design allows influencing the antenna pattern and the orientation of the main lobe by electrical means (e.g., remote electrical tilt and beam forming). Extensive studies for WCDMA systems reveal that antenna tilt is a highly responsive lever when it comes to shaping the cell footprint and the interference coupling with other cells [14]. Beam forming may be used to steer the direction of the antenna gain toward the area that is in outage (given that the position and orientation of the base stations are known, at least to some degree).

Besides the above-mentioned primary control parameters, which are employed to improve the coverage area, there are secondary control parameters. These are parameters that might require an update as consequence of a cell outage as such, or as consequence of the alteration of primary control parameters. For example cell outages as well as the triggered adjustment of e.g. reference signal power and antenna tilt are likely to induce new neighbor relations and hence neighbor cell lists need to be updated.

VI. Scenarios

In this section several scenarios are described that will be considered in the development and assessment of cell outage compensation methods. The appropriateness of the scenarios lies therein that they capture a diversity of case studies representing different network situations and where significant impact on COD and COC performance is anticipated, and as such, are likely to impact the specifics of the developed algorithms. For cell outage compensation, we limit ourselves to cases where an entire site or sector fails and do not consider particular channel or transport network failures. The following scenario descriptions specify assumptions regarding network, traffic, and environment aspects:

- *Impact of eNodeB density and traffic load* – In a sparse, coverage-driven network layout, little potential is likely to exist for compensating outage-induced coverage/capacity loss. In a dense, capacity-driven network layout, however, this potential is significantly higher, particularly when traffic loads are low.
- *Impact of service type* – The distinct quality of service requirements of different services affect the compensation potential. For instance, compensation actions may be able to alleviate local outage effects to handle only low bandwidth services.
- *Impact of outage location* – If cell outages occur at the edge of an 'LTE island' fewer neighbours exist to enable compensation. For outages in the core of such an 'LTE island', the compensation potential is larger.
- *Impact of user mobility* – If mobility is low, few users spend a relatively long time in an outage area. Alternatively, if the degree of mobility is high, many users spend a relatively short time in an outage area. The perceived outage impact depends on the delay-tolerance and elasticity of the service.
- *Impact of spatial traffic distribution* – If traffic is concentrated near sites, it is typically relatively far away from neighbouring sites and hence the compensation potential is limited. Alternatively, if traffic is concentrated 'in between' sites, the potential is larger.

Other possible scenarios that are deemed somewhat less significant are related to *propagation aspects* and the *UE terminal class*. As an example for the first aspect, note that e.g., a higher shadowing variation generally causes the outage area to be more scattered, providing more potential for surrounding cells to capture the traffic. Regarding the latter, note that the higher a UE's maximum transmit power is, the lower the need for outage compensation, since the UE may still be able to attach to a more distant cell even without compensation measures.

VII. Assessment Criteria and Methodology

Appropriate assessment criteria are required for comparison of different candidate COD and COC algorithms, and to assess the network performance improvement when the COD and COC algorithms are activated. The assessment criteria should also quantify the trade-off between the gains in network performance and deployment impact in terms of signalling and processing overhead, complexity, etc.

Denote with T_{fail} and T_{detect} the time instant when the failure occurred and when it is detected, respectively. A failure duration interval starts with the occurrence of a failure and ends with the elimination of the failure (e.g., by repairing the error involved), see Figure 3. A true detection is a detection which is reported by the cell outage detection mechanism during the failure duration interval. In contrast a false detection is reported outside the failure duration interval and is, as such, an erroneous detection.

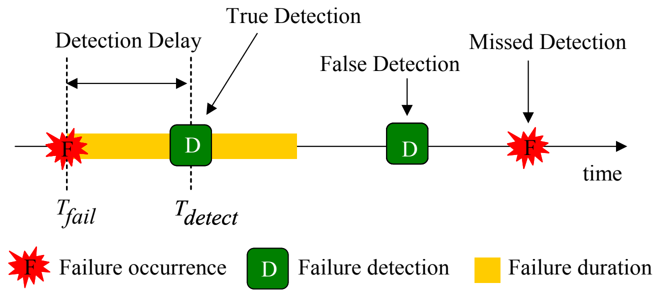

Figure 3 Cell outage detection events.

Denote with N_{fail} the number of failures during the observation period, and with N_{detect} and N_{false} the number of true and false detections, respectively. Suitable assessment criteria to evaluate the outage detection performance are: *detection delay* T_{detect} - T_{fail}; *detection probability* N_{detect} / N_{fail}; and the *false detection probability* N_{false} / (N_{false} + N_{detect}).

The assessment criteria for performance evaluation of the COC algorithms can be defined from a subset of the UE and eNodeB measurements, presented in Section IV, or based on the performance information available in the simulations models related to e.g. system capacity, provided coverage and quality of service (QoS), etc. For example, an important assessment criteria is *coverage*, which is defined as (N_{bin} – N_{bin_outage}) / N_{bin}, where N_{bin} is the number of pixels or bins in the investigated area while N_{bin_outage} is the number of pixels having average Signal to Interference Noise Ratio (SINR) or throughput lower than a pre-defined threshold.

Suitable criteria for assessing the deployment impact for cell outage detection and compensation are the signalling overhead, defined as number of messages (or bytes) per time unit, and processing overhead that is defined as amount of processing needed to detect or compensate the outage. Note that the signalling overhead can be assessed on the transport network (e.g. X2, S1, and O&M interfaces) and the radio network (e.g. between the UE and the eNodeB).

In order to illustrate the envisaged evaluation methodology for the COC we define three system states as presented in Figure 4. State A, denotes the pre-outage situation, state B is the post-outage situation without COC, and state C is the post-outage situation with COC. The red arrow indicates the time instant at which the cell outage occurs.

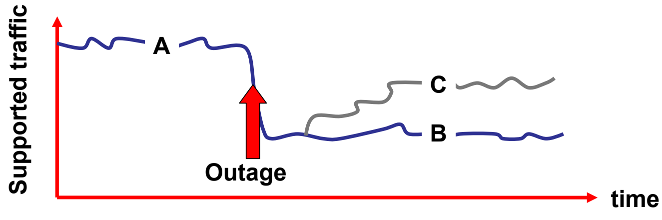

Figure 4 The system states before and after a cell outage event.

The proposed evaluation methodology for the assessment of the COC algorithm consists of the following steps:

Step 1 'Controllability and observability analysis' – Given the post-outage system state B, it should be determined which control parameters (see Section V) have the highest impact on the system performance. Furthermore, the most important UE and eNodeB measurements should be identified that can be used to timely observe the system state and performance with sufficient accuracy.

Step 2 'Design of COC algorithm' – Design of the self-optimisation algorithm aided by static/dynamic simulations. Given system state B and starting from the parameter settings in system state A, perform step-wise adjustments of the control parameters deemed most effective in the controllability study of *Step 1*. After each COC step the system performance should be measured in order to evaluate the impact of the previous COC decision(s). The COC steps consecutively adjust the control parameters until the algorithm decides that no further adjustments are needed and the system converges into a stable working state. It is important to determine the convergence time of the COC algorithm. Additionally, it is important here to compare the resulting system performance (with the COC adjustments) to either the optimal system performance that can be achieved or the situation when no COC adjustments are made in the system.

Step 3 'COC deployment assessment' – As a final step it is important to assess the performance of the algorithm developed in *Step 2*, considering the full dynamics of the state transition from state A to state B as well as the practical constraints such as e.g. availability of the measurements, duration of measurement intervals, measurement accuracy, time needed for the parameter adjustments etc. The impact on the resulting system performance (see state C in Figure 4) should be determined when the state transition and the practical constraints are taken into account.

VIII. Conclusion

The detection and compensation of outages in current mobile access networks is rather slow, costly and suboptimal. Herein, costly refers to the considerable manual analysis and required unplanned site visits that are generally involved, while suboptimal hints at the typical revenue and performance loss due to delayed and poor mitigation of the reduced coverage and capacity. The framework described in this paper addresses the shortcomings of today's practice and proposes an approach for automatic cell outage management and outlines the key components necessary to detect and compensate for outages. We argue that the detection and compensation of outages, which aims at alleviating the performance degradation, can be made autonomous, requiring minimal operator intervention. This means not only a faster and better reaction to outages, which decreases the revenue and performance losses, but also less manual work involved and, as such, OPEX.

We will continue our work with the following three steps. First, a *controllability study* will be carried out in order to assess to what degree the application of the different control parameters is effective in the compensation of outages, as well as to understand the relation between control parameters and performance indicators, e.g., coverage and throughput. In the subsequent *observability study* we will investigate which measurements, counters, etc, are most suitable for use in outage detection and compensation algorithms. As part of this, one line of work is to derive methods for obtaining X-maps. Lastly, we will *develop algorithms* for cell outage detection and compensation and evaluate their performance using the scenarios and assessment criteria presented in this paper.

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