Cell Outage Detection Based on Handover Statistics

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***Abstract*—This letter presents a novel cell outage detection algorithm based on incoming handovers statistics. The main advantage of the proposed algorithm is that it uses neighbor measurements that allow to detect outage in two cases. First, when the cell in outage is able to report performance indicators; second, when these indicators are not available because the base station is affected. To evaluate the proposed algorithm and compare it with other approaches, a set of tests has been carried out using an LTE simulator and in a live LTE network.**

***Index Terms*—Cell outage detection, self-healing, LTE, handover, real network.**

I. Introduction

The incorporation of automatic features into network management has become a key element in new generation mobile networks definition in the last few years. The 3rd Generation Partnership Project (3GPP) has included Self-Organizing Networks (SONs) as part of recent standards of mobile communications networks such as LTE (Long Term Evolution) [1] The main objective of the SONs is to reduce operational expenditures (OPEX) and capital expenditures (CAPEX) by automating optimization tasks and network maintenance.

SON functionalities are classified into three groups: Self-Configuration, Self-Optimization and Self-Healing. Self-Healing functions carry out the detection, diagnosis, compensation and recovery of network failures in an automatic manner. One of the fundamental use cases in Self-Healing is Cell Outage Management (COM) [2]. COM comprises Cell Outage Detection (COD) and Cell Outage Compensation (COC). A cell is in outage when it cannot carry traffic due to a failure. In this situation it is very important to identify the cell in outage as soon as possible to minimize the effects in the network. When the detected problem persists and cannot be solved immediately, the COC algorithm is executed to try to serve affected users by re-connecting them to neighboring cells until the fault is solved.

There are several methods to implement COD. In most cases [3], [4], the COD algorithm monitors Key Performance Indicators (KPIs) and alarms reported by cells to determine if they experience problems. Specifically, in [4], the authors propose a method to detect different types of network degradation including cells in outage. With this methodology it is possible to detect outage situations only if the evolved Node B (eNB) can supply KPIs from the cell in outage to the OSS (Operations Support System). However, if the outage affects the eNB, no KPIs will be available from the cell in outage. When this occurs, the only way to detect an outage in a certain cell is using information provided by its neighbor cells. In this line, in [5] the authors present a COD algorithm to detect outages based on the analysis of the KPIs reported by each cell which allows to determine if any of its neighbor cells is in outage. The effectiveness of this algorithm depends on the level of degradation in other cells caused by the cell in outage. This is an important limitation of the algorithm because in many cases a cell in outage does not cause a performance degradation in the neighbor cells. The COD algorithm proposed in [6] is based on the neighbor cell list reports. This algorithm can detect cell outages even when the eNB is affected since the detection is based on user measurements from the neighbor cells. User measurements are also used in [7], [8]. The algorithm presented in [7] is able to detect an outage in a femtocell scenario based on signal level measurements. In [8], the authors propose an algorithm to detect cells in outage based on user measurements combined with location information. However, the use of user measurements is the main drawback of all these approaches because the use of traces limits the bandwidth of the system and operators are unwilling to activate them.

In this letter a COD algorithm that overcomes the previous problems is presented. The proposed algorithm is based on the number of incoming handovers (inHO) measured on a per cell basis by neighboring cells. Specifically, the proposed algorithm monitors situations where the number of inHO becomes zero as a potential symptom of cell outage. The main advantages of the algorithm are that it is capable of detecting cell outages even if the eNB is also affected and that it uses performance counters that are available in the OSS. Due to the simplicity of the algorithm it is possible to make the detection immediately after collecting the KPIs. The proposed algorithm has been included in a patent application that has been filed on October 28, 2014 (application number PCT/SE2014/051270).

This letter also includes a set of experiments to evaluate different COD algorithms. Results show that an important improvement can be achieved when the detection method is based on neighbor measurements. These experiments have been carried out both using a simulation tool and in a live LTE network.

II. System Model and Problem Formulation

An eNB is a base station that controls one or more (typically 3) cells, Fig. 1. When there is a cell in outage in a network, different situations can occur. On the one hand, in some cases, the fault that causes the outage affects only the related cell. In

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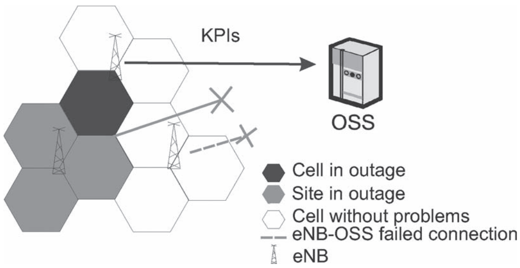

Fig. 1. Cases of cell outage.

this situation, the related eNB can provide the KPIs from this cell indicating that the cell is not available due to a problem. On the other hand, in other cases, the outage affects the eNB. When this occurs there are no KPIs available in the OSS from any cell of the site in outage. Therefore, if the detection algorithm is based on monitoring the value of different KPIs for each cell, this outage situation cannot be detected. Other possible detection algorithms can be based on the lack of KPIs for a certain cell. However, such a lack of KPIs does not always indicate an outage problem (e.g., an eNB-OSS connection failure may cause a lack of KPIs although the related cell is active).

To assess different COD algorithms, an LTE system model is proposed. Firstly, this system model (Cell Outage Model) allows to simulate diverse outage situations so that the different detection algorithms can be tested. Secondly, to show the limitations of the algorithms, the proposed system model also includes situations that can be detected as outage problems even when the cell operates properly.

The proposed Cell Outage Model includes different cases of cell outage, Fig. 1:

- Cell outage that does not affect the eNB. In this case there are KPIs available from the cell in outage, although most KPIs are likely to be zero. The eNB must indicate that the cell is not active using KPIs related to availability (availability KPIs). In some cases the cell is automatically locked due to a problem. However, there are also other situations in which the cell is switched off by the operator for maintenance tasks or due to energy saving reasons. In this latter case, switched off cells should not be considered as cells in outage.
- Site outage. In this situation the eNB is affected by the fault so that all cells covered by this eNB are impacted. As a consequence, no KPIs can be collected from the OSS.
- Cell is not in outage, but there is a failure in eNB-OSS connection. The Cell Outage Model implemented here includes this fault because this situation can be erroneously detected as an outage problem by some detection methods. When an eNB loses the connection with the OSS the KPIs cannot be collected, however, the site is carrying traffic.

The Cell Outage Model can be applied to any type of LTE RAN simulator to evaluate different COD algorithms.

III. COD Based on Incoming Handovers Statistics

The proposed COD algorithm allows to detect a cell in outage even when the eNB is affected and KPIs from that cell are not available. To achieve this objective the algorithm is based on neighbor measurements. Specifically, the proposed algorithm monitors the number of inHO on a per cell basis. If this number becomes zero for a certain cell the algorithm selects the cell as a candidate cell in outage.

The algorithm includes a configurable parameter, called *measurement period*, which determines the time period between two executions of the algorithm. This period has an important impact on the detection delay of the algorithm. The lower the measurement period is, the faster the detection is. However, this parameter has to be high enough to ensure that the collected KPIs are significant statistically and depends on the periodicity of updating KPIs in the OSS.

The algorithm is composed of three phases that are detailed in Algorithm 1.

Algorithm 1 COD based on inHO

Input: inHO and availability KPIs from all cells
Output: Cell outages detected

For each cell do the following steps:
1. Calculate the number of inHO in the last $measurementperiod\ (actualho)$

2. Calculate the number of inHO in the previous $measurementperiod\ (previousho)$

3. Apply the following rule

3.1. if $(actualho = 0)\ AND\ (previousho > 0)$ then
  3.2. if KPIs are available
    Check the availability KPIs
    3.3. if (ISNOT active) AND (ISNOT switched off)
      The cell is selected
    end
  else
    The cell is selected
  end
end

Firstly, the total number of inHO for each cell in the last *measurement period* (e.g., one hour) is calculated $(actualho)$. In the second step, the same calculation is made for the previous $measurement\ period\ (previousho)$. In the last step, a set of rules is applied to determine the final output of the algorithm. The result of the first condition (i.e., condition 3.1) is a set of cells that may be inactive in this *measurement period*. Some of these cells might have been switched off by the operator for maintenance tasks or energy saving reasons. Moreover, some cells might lead to false positives due to very low traffic. In these both cases, it is necessary to check the availability KPIs (i.e., condition 3.3) to do the final selection. Only the cells that are inactive in the current *measurement period* but have not been switched off by the operator are selected as cells in outage. Finally, it is possible that there are no KPIs available from some cells. In these cases, the eNB has been affected by the outage and the related cells do not fulfill the condition 3.2. The final result of the algorithm indicates the cells that are in outage.

IV. Results Analysis

This section presents the results obtained in the COD algorithms analysis. A set of tests has been carried out to evaluate the effectiveness of the proposed algorithm and compare it with other approaches. The study has been made by using both simulations and real network tests.

The approaches that have been tested are:

- COD based on availability KPIs (Availability KPIs). This method consists of monitoring the availability KPIs that an eNB sends to the OSS indicating whether a cell is locked due to a problem or it is switched off due to maintenance tasks or energy saving reasons. Only the first case should be considered as outage. The algorithms presented in [3], [4] follow this approach.
- COD based on the lack of KPIs (Lack of KPIs). This algorithm tries to detect a possible cell outage by monitoring that the KPIs of each cell are always reported in each measurement period. If there are no KPIs for a certain cell, then the algorithm concludes that the cell is in outage.
- COD based on inHO statistics (inHO statistics). This algorithm is the one proposed in this letter and has been described in detail in Section III.

A. Simulation Tests

The simulation tests have been executed using a dynamic LTE system level simulator implemented in MATLAB [9]. This simulator represents the LTE radio access network and allows to estimate the most important KPIs for each cell and each adjacency. The Cell Outage Model proposed in Section II has been applied to this simulator to assess the different COD algorithms described in the same section.

The simulation scenario is a part of a real network composed of 75 cells. The simulator includes a user mobility model that allows to simulated users with different speeds. The simulator also includes a handover (HO) algorithm to generate realistic HO statistics. The HO algorithm considered in this work is based on the A3 event. When the signal level received by an user from a neighbor cell is higher with a margin (HO_off) than the signal level received from the serving cell, the HO is executed. Table I summarizes the main configuration parameters of the simulations.

TABLE I
SIMULATION PARAMETERS

Parameter	Configuration
Cellular layout	75 cells (25 eNBs)
Transmission direction	Downlink
Carrier frequency	2.0 GHz
System bandwidth	1.4 MHz
Propagation model	Okumura-Hata Log-normal slow fading, $\sigma_{sf} = 8$ dB and correlation distance=50m
Channel model	Multipath fading, ETU model
Mobility model	Random direction, 3, 10, 50 km/h
Base station model	Tri-sectorized antenna, SISO, $P_{TX_{max}}$ =43 dBm
Handover	Triggering event = A3 Measurement type = RSRP HO_off = 3 dB
Time resolution	100 TTI (100 ms)

TABLE II
SIMULATION RESULTS

Result	Availability KPIs	Lack of KPIs	inHO statistics
FalseNegativeRate	84%	16%	5.9%
FalsePositiveRate	0%	0.9%	0%

In total, 307 outage situations have been generated in the simulation: 49 are outages that do not affect the eNB so that KPIs from the cell are available and the related availability KPI indicates the outage situation; and 258 are outages that affect the eNB so that KPIs from the cell are not available in the OSS. In addition, 141 eNB-OSS failed connections have been simulated. The different COD algorithms have been activated during the simulation to assess their effectiveness.

Table II presents the results in terms of the false positive rate and the false negative rate for each COD method. The false positive rate is the percentage of wrong detected cases among the total outage cases and the false negative rate is the percentage of no detected cases among the total of normal cases simulated.

The Availability KPIs algorithm obtains a 0% of false positives but a 84% of false negatives. This value coincides with the frequency of occurrence of the outage cases with the eNB affected because this method cannot detect an outage problem when KPIs are not being reported.

The Lack of KPIs algorithm has nonzero false positive and false negative rates. The value of the false negative rate (16%) coincides with the frequency of outages with available KPIs. Moreover, other important disadvantage of this method is that it produces 0.9% of false positives (equal to the frequency of OSS failed connections) since the algorithm identifies every eNB-OSS failed connection as outage.

It is possible to define an algorithm that combines the Availability KPIs and the Lack of KPIs methods. With this algorithm the false negatives of both methods can be eliminated. However, this algorithm would have an important number of false positives since the algorithm would detect as cells in outage all the failed eNB-OSS connection situations.

Finally, the proposed inHO statistics algorithm has been tested. The results show that this method is able to detect most simulated outages, leading to a low percentage false negatives (5.9%). This situation is related to cells with low traffic so that they have a low impact on the network performance. When a cell with low traffic is in outage, the number of inHO in the current *measurement period* may be equal to zero. The algorithm is able to detect the outage only if the number of inHO in the immediately preceding *measurement period* is nonzero. However, it is possible that the cell does not manage any inHO in the earlier *measurement period*} due to the low traffic. In this case the algorithm cannot detect the outage problem, resulting in a false negative.

The proposed algorithm produces a 0% of false positives, considering the simulated situations, since the availability KPIs allow to detect the potential false positives cases (i.e., cells with very low traffic that have not inHO in a certain *measurement period* although no problems are affecting it). However, in a real network new situations may occur that produce a false positive (e.g., a cell with no inHO during a certain hour and no KPI

TABLE III
AVERAGE NUMBER OF CELL OUTAGES PER DAY IN A REAL NETWORK

Availability KPIs	Lack of KPIs	inHO statistics
15.78	50.1	25.2

TABLE IV
INHO STATISTICS ALGORITHM RESULTS

Parameter	Results
Candidate cells	2271
Active cells (potential false positives)	2220
Switched off cells	32
Final output (cells in outage)	19

available due to an OSS connection failure). Nevertheless, since those situations that can produce a false positive of the proposed algorithm are not very common, the real percentage of false positives will be very low.

B. Real Network Tests

To complete the analysis of the proposed COD algorithm, a set of tests in a real LTE network has been performed. The network includes approximately 8000 LTE cells. The COD methods under study have been active during 9 days and executed every hour, which is the periodicity of KPIs updating in the OSS. However, as stated before, the algorithm can be executed with a periodicity of minutes if the KPIs updating is made more often (e.g., 15 minutes).

Table III shows the obtained results of the analysis which represent the average number of cell outages detected per day.

The number of cell outages detected by the Availability KPIs method is the lowest. Since this algorithm is not able to detect outages that affect the eNB, the false negative rate may be very high.

The Lack of KPIs method only detects the outages that affect the eNB. The number of false positives may be high since the eNB-OSS failed connections are detected as outage problems. This method cannot detect the outage cases that affect only a cell.

The result shown for the proposed inHO statistics algorithm is the total number of cell outages. This method leads to a high number of candidate cells in outage as a result of the first condition (i.e., condition 3.1). The reason for this is that this algorithm detects all the cells that seems to be inactive in the current *mesurement period* (i.e., cells with inHO equal to zero). This result may include cells that are in outage, cells that have been switched off and cells with a very low traffic. If a cell has a problem with the eNB-OSS connection but does not have problems to serve traffic, then this cell is not detected as faulty (the algorithm does not have the same false positives as the Lack of KPIs method). By checking the availability KPIs, it is possible to remove the cells that have been manually switched off and the active cells from the final solution (eliminating most of the potential false positives of the algorithm). Table IV shows an example for one day.

As described in Section IV-A, some situations may produce false positives for the proposed method so that the false positive rate of the algorithm is the probability of occurrence of these situations (e.g., a cell with no inHO during a certain hour and no KPI available due to an OSS connection failure). Nevertheless, this type of situations are not common in a real network.

The proposed algorithm may present a nonzero false negative rate. If a cell does not carry traffic during some hours and has an outage at this moment, the algorithm cannot detect it because the number of inHO in the previous *measurement period* is equal to zero. It is important to point out that this limitation only affects cells with very low traffic that do not have a significant impact on the overall network performance. Another false negative situation is that if a cell suffers outages whose duration is less than the algorithm periodicity, it is not possible to detect them. Therefore, the false negative rate of the proposed algorithm can be calculated as the probability of occurrence of outages in a cell with no traffic and outages with a duration less than the algorithm periodicity.

Most detected cell outages are problems that have lasted a few hours but there are some cases of outage that have affected a cell during many hours even days. The detected cases have been confirmed by the operator.

V. CONCLUSION

A cell outage detection algorithm has been proposed in this letter. The algorithm is based on the number of incoming handovers statistics and allows to detect a cell outage when KPIs from the cell are either available or not. A set of simulations and real network tests have been carried out to evaluate the proposed detection method and compare it with other approaches. The results show that the proposed algorithm is able to detect most outage situations in a real network. The main limitation of the algorithm is that the cell outages that affect cells with very low traffic cannot be detected. However, these outage situations have a low impact in the user experience and in the overall network performance.

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