Automatic Detection of Sub-optimal Performance in UMTS Networks based on Drive-test Measurements

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Abstract— **This paper presents a methodology for the automatic detection of sub-optimal performance in UMTS networks based on drive-test measurements. The proposed methodology can be seen as a first step towards the more ambitious objective of implementing Self-Organising Network (SON) concepts in future wireless networks. In fact, the lessons learnt from real UMTS case studies enable the identification of key issues related to self-optimisation whose relevance can be more difficult to attain theoretically. In particular, this paper presents algorithms targeting the identification of coverage holes, cell overlaps and cell overshooting. Relevant quality indicators are identified in each case. A case study with real data extracted from a medium-size European city is presented to illustrate the methodology.**

Keywords: ***Automated optimisation, Key Performance Indicators, UMTS, coverage, overlap, overshooting.***

I. INTRODUCTION

Third-generation (3G) mobile communication systems have seen widespread deployment around the world. The remarkable milestone of 500 million 3G/UMTS subscriptions worldwide was already reached in early 2010 [1]. Operators are always investing large budgets to deploy and upgrade their networks. The necessity to reduce costs clearly indicates that the process of network deployment/optimisation must be carried out more efficiently. Self-Organising Networks (SON) [2] aiming to configure and optimise the network automatically are seen by operators as an opportunity to reduce costs. Focusing on the optimisation of a 3G system two phases can be distinguished [3]: RF optimisation, whose objective is to guarantee the required coverage, avoiding excessive cell overlap or cell overshooting by optimising the setting of RF parameters (e.g. pilot power, antenna down-tilt, etc) and service parameters optimisation which includes the setting of admission and congestion control thresholds, maximum downlink power per connection, etc. This paper deals with the automatic detection of sub-optimal operation in UMTS networks based on drive test measurements. In fact, this paper extends the case study presented in [4], which proposed the automatic detection of coverage holes, by exploiting the identification of the so-called *clusters* as a means of assessing the coverage problems in a cell with a higher degree of detail with the definition of additional metrics. Moreover, this paper extends the capabilities for the automatic detection of RF problems by also defining algorithms to detect cell overlap and cell overshooting. The rest of the paper is organised as follows. In Section 2, some considerations for the detection of sub-optimal RF operation by using drive tests are presented. Sections 3, 4, and 5 present the detection procedure for three specific problems (sub-optimal coverage, cell overlap and cell overshooting). Section 6 describes the proposed detection tool. Some illustrative results using real drive test measurements are shown in Section 7 and Section 8 summarises the conclusions.

II. DETECTION OF SUB-OPTIMAL RF OPERATION

For the automatic detection of sub-optimal operation, the actual network performance needs to be captured. Clearly, the more accurate this picture is, the more efficient the optimisation process can be expected. In practice, the network operator can collect information about the network status from different sources (network counters, measurement reports and drive tests [3]). Drive tests are carried out by one or several specialised terminals equipped with a Global Positioning System (GPS) able to record certain measurements and the position where each measurement has been taken. When carrying out drive tests, it is very important to specify the trajectory of the testing vehicle to ensure the acquisition of measurements in the areas where the real traffic is generated.

A. Considered optimisation targets

Three main RF optimisation targets are considered in this paper for a given cell under study:

- *Minimise coverage holes:* A coverage hole is defined as a geographical region inside the planned coverage area of a given cell in which no communication can be established because the signal level is below the sensitivity threshold.
- *Minimise cell overshooting:* A cell will have overshooting problems when it is detected at distances much larger than its planned coverage area.
- *Minimise cell overlap:* Cell overlap is defined as the situation in which a cell is detected as a possible server outside its expected coverage area and inside the coverage area of a neighbour cell.

B. Inputs for the automatic detection process

The Key Performance Indicators (KPI) used for the detection of undesirable performance in the above targets are [5]:

- *CPICH RSCP (Common Pilot Channel Received Signal Code Power*).
- *CPICH Ec/Io*.
- *Uplink transmission power* (P_T).
- *Active Set (AS) and Monitored Set (MS) lists*.

C. Input data significance

For a reliable sub-optimal operation detection, it is necessary to have drive test measurements in a large percentage of the planned coverage area of the sector under study. This can be quantified with the proposed drive test validation index K(%)

defined as the percentage of area measured by the drive test with respect to the total area that could be potentially measured. As drive tests are carried out along roads, not all the area of a given cell can be measured in a drive test campaign (e.g. indoor areas). Consequently, this potentially measurable area should be computed depending on the planned coverage area of the sector and a fraction of this area corresponding to streets that could be obtained from a previous analysis of the geographical characteristics of the area under study.

III. DETECTION OF SUB-OPTIMAL COVERAGE

In [4], a general framework for the automated detection of sub-optimal coverage was presented. The process was formulated in the form of hypotheses test against the sub-optimal operation for a number of established targets applied over a cell under study. Hypotheses are reinforced by a likelihood index F that is increased every time that a given condition evaluated over a certain KPI (or combination of KPIs) is met. Considering that a total of N_c conditions $c(i)$ $i=1,...N_c$ are evaluated, each condition will have an associated weight α_i depending on the relevance of the condition for the corresponding optimisation target. The likelihood index F is defined as ($0\leq F\leq 1$):

$$F=\sum_{i=1}^{Nc}\alpha_i U(c(i)) \Big/ \sum_{i=1}^{Nc}\alpha_i \qquad (1)$$

where $U(c(i))$ takes the value 1 if condition $c(i)$ is fulfilled and 0 otherwise. The weights α_i can be fixed according to certain operator's policies. For the case of using only drive test measurements, Fig. 1 shows the process for the detection of sub-optimal coverage based on [4]. For a given sector, the samples to be analysed are selected according to Voronoi's tessellation [6] (i.e. all the points whose closest cell is the cell under study). With the set of filtered samples, four conditions are evaluated (see Fig. 1). With the availability of drive tests, the methodology can determine the specific geographical areas (referred here as *clusters*) where the sub-optimal behaviour is detected. This is done by grouping the positions with a particular sub-optimal behaviour and by analysing these *clusters* individually. This enables the association of a more detailed metric to have different quantitative levels at which the coverage problem is present (e.g. observing RSCP levels below -108 dBm indicates poorer performance than -98 dBm). To this end, a likelihood index F_k for each detected cluster k is determined. The term F_k is computed in a similar way as (1) but now evaluating the conditions over the samples in each cluster. As for the RSCP condition, it is now evaluated with different decreasing threshold values $RSCP_{cov1}$, $RSCP_{cov2}$. Besides a general warning about undesirable coverage in a given cell (i.e. $F>F_{min}$ as in [4]), a list of clusters where coverage problems have been identified is provided including information about each one (cluster location, size and likelihood index F_k). Moreover, the overall degree of coverage problems taking into consideration all the identified clusters is quantified by the metric $S_{Coverage}$ ($0\leq S_{Coverage}\leq 1$):

$$S_{Coverage}=\sum_{k=1}^{N_{clusters\_Coverage}}\frac{F_k\cdot N_{Coverage,k}}{N_S} \qquad (2)$$

where $N_{clusters\_Coverage}$ denotes the number of clusters with coverage problems in the cell, F_k is the likelihood index of the k-th cluster, $N_{Coverage,k}$ is the number of samples for the k-th cluster and N_S is the number of samples in the drive test inside the planned coverage area of the cell under study.

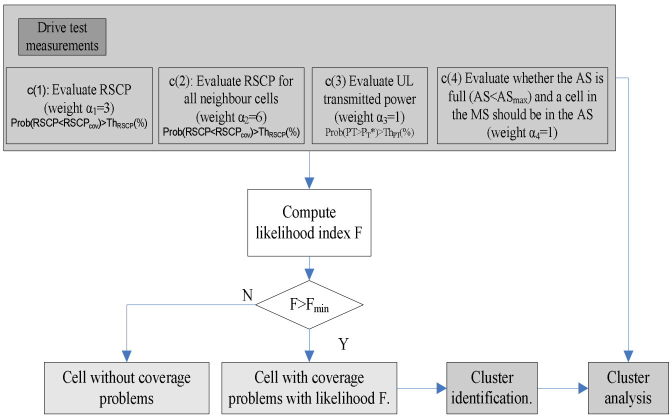

Fig 1.- Detection of sub-optimal coverage algorithm.

IV. DETECTION OF CELL OVERLAP

The cell overlap detection algorithm is also formulated in the form of hypotheses test reinforced by a likelihood index. In contrast to the coverage case, where a reference coverage footprint can be defined for the cell, there is not such clear criterion to define the potential area where a cell can generate overlaps towards neighbouring cells. Therefore, in this case the analysis is done for all the drive-test available samples located at a distance considerably higher than the planned coverage area for the study cell where this cell is detected with CPICH RSCP above a threshold set to $RSCP_{best}$-M_{SHO}, where $RSCP_{best}$ is the RSCP of the best server and M_{SHO} is the soft handover margin. Then, the analysis is directly addressed from a cluster perspective. Each valid cluster is analyzed separately and the value of the likelihood index F_k for the k-th cluster is determined to quantify the degree of the detected overlap problems. The conditions evaluated to compute the term F_k over the samples in each cluster, are:

- c(1): The RSCP of the neighbour cell is higher than the coverage threshold ($RSCP_{cov}$) for more than Th_{RSCP}(%) of the samples of the cluster. The neighbour cell is defined as the cell with lowest distance to the sample.
- c(2): The CPICH Ec/Io degradation in the neighbour cell (due to the overlap of the study cell) is higher than $Th_{deg\text{-}overlap}$.
- c(3): The AS is full and the studied cell causing overlap is not in the AS for more than Th_{AS}(%) of the cluster samples.

The algorithm output is a list of clusters with overlap problems including information about each one (cluster location, size and likelihood index F_k). Moreover, in order to quantify the overall degree of overlap problems caused by the cell under study the following metric $S_{Overlap}$ is defined as ($0\leq S_{Overlap}\leq 1$):

$$S_{Overlap}=\sum_{k=1}^{N_{clusters\_overlap}}\frac{F_k\cdot N_{Overlap,k}}{N_S} \qquad (3)$$

where $N_{clusters\_overlap}$ denotes the number of overlap clusters in the cell, F_k is the likelihood index of the k-th cluster, $N_{Overlap,k}$

is the number of samples with overlap problems for the k-th cluster and N_S is the number of samples in the drive test inside the planned coverage area of the cell suffering the overlap.

V. DETECTION OF CELL OVERSHOOTING

The cell overshooting detection algorithm is formulated in a similar way as the cell overlap. In this case, the analysis is done for all the drive-test samples located beyond the first ring of neighbouring cells of the study cell with a CPICH RSCP higher than certain threshold $RSCP_{overshoot}$. Each valid cluster is analysed separately and the value of the likelihood index F_k is determined for each cluster in order to quantify the degree of the detected overshooting problems. The term F_k is computed evaluating the conditions below:

- c(1): The CPICH_RSCP of the study cell is higher than $RSCP_{overshoot1}$ for more than $Th_{RSCPovershoot1}$(%) samples.
- c(2): The CPICH_RSCP of the study cell is higher than $RSCP_{overshoot2}$ for more than $Th_{RSCPovershoot2}$(%).
- c(3): The CPICH Ec/Io degradation in the neighbour cell is higher than the threshold $Th_{deg\text{-}overshoot}$.

The algorithm output is also a list of valid clusters with the corresponding information for each cluster. Moreover, the metric $S_{overshoot}$ is defined to quantify the overshooting problems caused in the cell under study ($0 \le S_{overshoot} \le 1$) as:

$$S_{Overshoot} = \sum_{k=1}^{N_{clusters\_overshoot}} \frac{F_k \cdot N_{Overshoot,k}}{N_S} \qquad (4)$$

where $N_{clusters\_overshoot}$ denotes the number of overshoot clusters in the cell, F_k is the likelihood index of the k-th cluster, $N_{overshoot,k}$ is the number of samples with overlap problems for cluster k-th and N_S is the number of samples inside the planned coverage area of the cell suffering the overshooting.

VI. SUB-OPTIMAL PERFORMANCE DETECTION TOOL

This section describes a software tool that automates the detection of the sub-optimal performance (i.e. coverage, overshooting and overlap) for a certain cell under study (see Fig. 2). This software takes as an input the data obtained in a drive-test, the network topology and the configuration parameters. In particular, information related to the different Node-Bs location, number of sectors per Node-B, antenna configuration for each cell (i.e. azimuth and downtilt), CPICH channel power, etc. is necessary. Making use of the network topology and configuration input, the optimisation tool calculates the Voronoi tessellation [6] of the region to determine the theoretical cell coverage area. Then, for each cell, the tool makes a filtering process to determine which measurements of the entire drive test must be selected depending on the specific problem to be detected. The filtered drive test measurements are used for the evaluation of each specific problem as explained in previous sections. Then, the detection process carries out first the general analysis (at cell level) in the case of coverage problems followed by the detailed analysis (at cluster level) in all the cases. The final output is a ranking of cells for each analysed problem in descending order of the indicators ($S_{coverage}$, $S_{overlap}$ and $S_{overshoot}$). For each cell, the drive test validation index K, and a list of clusters with their corresponding F_k are also presented. For the coverage case, the general likelihood index F is also presented for each cell.

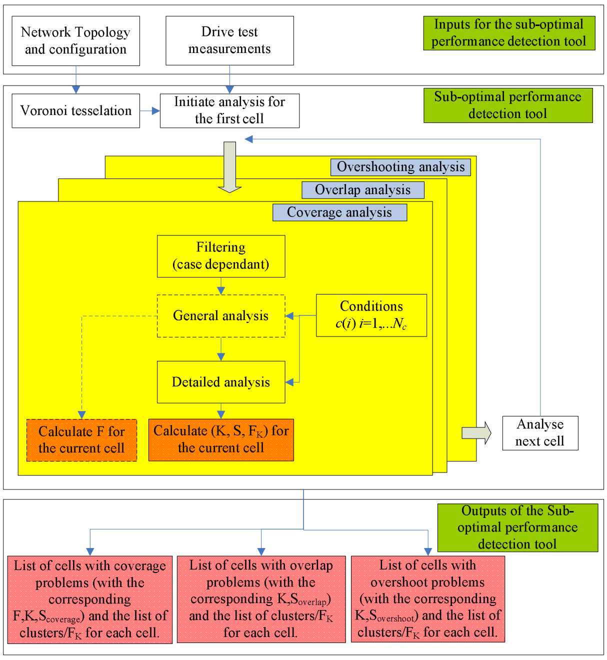

Fig 2.- Sub-optimal performance detection tool description.

VII. RESULTS

A case study to illustrate the sub-optimal performance detection methodology is described in this section. Drive-test data was collected in an urban area of a medium-size European city consisting on 24 tri-sectorial Node-Bs. Each of them is identified as Cell_x_y where x is the Node-B identifier and y is the sector of this Node-B. Two drive test campaigns were done in two different days. In the second day, the CPICH transmitted power for all the cells was increased. The considered algorithm parameters are given in Table 1.

Table 1.- Considered thresholds.

Threshold	**Value**	**Threshold**	**Value**
$RSCP_{cov}$	-88dBm	$Th_{deg\text{-}overlap}$	-3dB
$RSCP_{cov1}$	-98dBm	$Th_{deg\text{-}overshoot}$	-6.86dB
$RSCP_{cov2}$	-108dBm	Th_{AS}	90%
Th_{RSCP}	50%	$RSCP_{overshoot}$	-110dBm
P_T*	-1dBm	$RSCP_{overshoot1}$	-100dBm
Th_{PT}	90%	$RSCP_{overshoot2}$	-90dBm
AS_{max}	3	$Th_{RSCPovershoot1}$	50%
M_{SHO}	3dB	$Th_{RSCPovershoot1}$	50%

The outcome of the automatic sub-optimal performance detection algorithm is shown in Table 2 for both days. As for the coverage, it can be seen that the list of most relevant cells identified by the algorithm coincides on both days. However, the value of the $S_{Coverage}$ metric is significantly reduced on the second day which indicates the expected influence of the pilot power increase, which tends to improve the cell coverage footprint. This indicates that the proposed algorithm has been able to capture the changes in the radio network configuration.

As for the overlap and overshooting, again mainly the same cells are identified in both days. It can be also observed that the metrics $S_{Overlap}$ and $S_{Overshoot}$ for the second day tend to increase in comparison to the first day. Again, this represents the expected influence of the pilot power increase, which tends to extend the cell coverage footprint and, therefore, to increase the cell overlap and the cell overshooting.

Table 2.-Outcome of the analysis

	First day		Second day	
Cell coverage analysis	Cell	$S_{coverage}$	Cell	$S_{coverage}$
	Cell_15_01	0.167	Cell_15_01	0.070
	Cell_18_01	0.139	Cell_18_01	0.068
	Cell_16_03	0.138	Cell_16_03	0.063
Cell overlap analysis	Cell	$S_{overlap}$	Cell	$S_{overlap}$
	Cell_14_02	0.143	Cell_14_02	0.172
	Cell_6_02	0.106	Cell_6_02	0.156
	Cell_13_02	0.102	Cell_13_02	0.148
Cell overshooting analysis	Cell	$S_{overshoot}$	Cell	$S_{overshoot}$
	Cell_6_02	0.165	Cell_6_02	0.190
	Cell_13_01	0.114	Cell_9_01	0.187
	Cell_9_01	0.078	Cell_14_03	0.145

Let's focus on a specific region of the considered scenario as shown in Fig. 3 during the first day campaign. It consists of 6 tri-sectorial Node-B. Each sector is supposed to cover a range of 120º. Green arrows represent the pointing direction of the different antennas. Drive test measurements were carried out along several streets as indicated in yellow. The identified clusters related to coverage, overlap or overshooting problems are shown in this figure. On the other hand, Table 3 shows the cells with sub-optimal performance and their associated metrics, i.e. the drive test validation index K(%) for the victim cell and the likelihood of the problem quantified by the terms $S_{coverage}$, $S_{overshoot}$, $S_{overlap}$. The cell that is the source of the problem is identified for the overlap and overshooting cases.

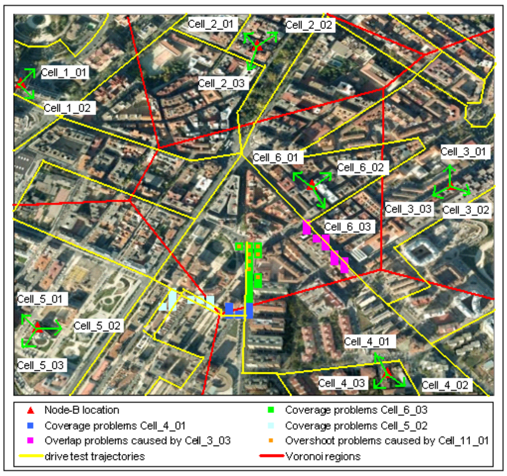

Fig 3.- Location of the identified clusters.

A rather large cluster indicating coverage problems has been found in Cell_6_03 (see Fig. 3) with a likelihood F_1=0.4 (see Table 4). Other clusters indicating coverage problems have also been detected. In particular, Cell_4_01 has a small cluster with a relatively high likelihood (F_1=0.6) and Cell_5_02 has two clusters with $F_1=F_2=0.2$. An overshooting problem caused by Cell_11_01 to Cell_6_03 has also been identified. Cell_11_01 is located in the second ring of neighbouring cells and its location is not presented in Fig. 3. Moreover, Cell_6_03 suffers a cell overlap caused by Cell_3_03.

Table 3.- Detected sub-optimal performance

Coverage holes			
Cell		K(%)	$S_{coverage}$
Cell_6_03		48.42	0.126
Cell_4_01		35.73	0.068
Cell_5_02		32.25	0.014
Cell Overlap			
Victim cell	Source cell	K(%)	$S_{overlap}$
Cell_6_03	Cell_3_03	48.42	0.019
Cell Overshooting			
Victim cell	Source cell	K(%)	$S_{overshoot}$
Cell_6_03	Cell_11_01	48.42	0.043

Table 4.- Number of clusters for the different cells.

	Cell_6_03	Cell_4_01	Cell_5_02
Num. of coverage clusters	1 (F_1 =0.4)	1 (F_1 =0.6)	2 ($F_1=F_2=0.2$)
Num. of overlap clusters	1 (F_1=0.25)	0	0
Num. of overshoot clusters	1 (F_1 =0.25)	0	0

VIII. CONCLUSIONS

This paper has addressed the automatic detection of sub-optimal performance in UMTS networks based on drive-test measurements. In particular, several algorithms have been proposed for pursuing the minimisation of coverage holes, cell overlap and avoidance of cell overshooting. For each case, relevant quality indicators have been identified and a number of validation metrics defined. A case study with real data extracted from drive-testing a medium-size European city has been presented. The proposed methodology and the validation results are claimed to be very valuable, not only for the UMTS optimisation process itself but also on a longer-term perspective. Lessons learnt from real UMTS case studies enable the identification of key issues (related to self-optimisation in general) whose relevance can be more difficult to attain from a theoretical/simulation point of view. This can provide valuable insight for future LTE-SON.

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