Signaling-based radio optimization in WCDMA networks

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Abstract

Coverage extension and quality, cell power utilization, neighbor cells ranking and other information normally provided by expensive field measurement campaigns can alternatively be extracted from signaling monitored in the Radio Network Controller. This paper, after reviewing a set of key performance metrics and optimization solutions validated experimentally in live networks, shows how automation benefits an Operator radio network planning department by increasing efficiency and reducing the operational expenditures up to an estimated 40%. Moreover, the paper explains how the proposed optimization method could evolve into an autonomic solution.

1. Introduction

Radio access optimization in cellular networks is traditionally based on drive tests and prediction tools, though they present several limitations in terms of statistical reliability and costs. While predictions can be effectively applied during pre-launch optimization and drive tests are essential to explore the radio environment in specific locations, the identification of radio limitations in wide areas of mature networks requires an approach based on events monitoring in the Radio Network Controller (RNC), considered as the concentration point of all the measurements reported by User Equipment (UE) and Node B.

The neighbor cells assessment based on event counters and Key Performance Indicators (KPIs) obtained by post-processing RNC signaling was addressed in [1] and [2]. In [3], the performance assessment was extended to cell coverage and interference. These metrics were submitted to the daily practice of an Operator planning department. Section 2 lists those that can be used for ultimately improving the quality of end user experience [4]. In section 3, in order to guarantee an effective utilization of the information by the final users, such as radio planners, KPIs are combined into cell behavior profiles, describing the predominant characteristics of a cell [3]. Section 4 explains how the entire process was automated by engineering the data collection and processing and lists the necessary steps in order to make the process fully autonomic. The process was validated by performing extensive optimization campaign in a live single vendor network. However, since all the needed metrics are extracted from signaling fully defined in the standards ([5], [6] and [7]), a similar solution could be deployed in a multi-vendor environment. Finally, section 5 tackles some aspects of estimating the operational expenses (OPEX). Though it is difficult to exactly quantify the savings obtained by implementing signaling-based optimization, it is a fact that costs are reduced by replacing extensive drive test campaigns dedicated to coverage and neighbors verification with a statistical evaluation of cells behavior.

2. Key Performance Metrics

The following sections list all the metrics needed for the optimization of neighbor relations, cell coverage and the detection of capacity shortages.

2.1. Neighbor cell statistics

Neighbor cells ranking must take into consideration, together with the number of soft/softer handover (SHO) events, indicators describing the quality of the handover process. The KPIs proposed in [1] were submitted to the daily practice of a planning and optimization department. The following were selected to measure how relevant an intra-frequency neighbor is for the correspondent source cell.

- \textit{SHOshare}: the percentage of addition (1a) and replacement (1c) events related to the target when the source is in active set, reported in \textit{RRC Measurement Report} messages [5]
- \textit{ActiveSetProbability}: the probability for the target cell to be in active set with the source, expressed by the percentage of time spent by the source cell in SHO with the target
By comparing the above indicators, it is possible to measure the quality of the handover. In fact, if a specific neighbor cell has an ActiveSetProbability that is much lower than the SHOshare, it most probably is an unstable target, which is added frequently but for a short time only to the active set of the source cell.

Similarly, in case of Inter-System handover (ISHO) neighbors, the relevant indicators are:
- **ISHOshare**: the percentage of BSIC verification procedures for a specific target GSM cell
- **ISHOSuccessRatio**: the percentage of successful ISHO procedures towards the target GSM cell, which measures the quality of the adjacent cell

Complementary information about the inter-system handover effort is given by the time spent in verifying the cell identity, which is the average BSIC verification time; some problematic targets can be suitable in terms of signal strength (RSSI) but, once selected for the ISHO, they are characterized by high BSIC verification time and low BSIC verification success ratio due to DL interference on the target or BCCH-BSIC re-use.

Similar performance indicators can be defined for inter-frequency procedures.

All the indicators mentioned so far can be extracted from standard RRC messages defined in [5], such as Measurement Reports, Active Set Updates, Handover to UTRAN Commands.

The correct implementation of the indicators is obtained tracing the evolution of the handover processes in RNC, in order to attribute the handover events to the appropriate cells in active set.

### 2.2. Coverage and Capacity statistics

The coverage and power measurements reported by UE and Node B to the RNC can be used to provide a statistical evaluation of the coverage behavior of a cell. Compared to drive tests, this approach is less detailed in terms of traffic positioning but much more reliable for the description of the predominant behavior of the cell, since it reflects the real subscriber locations.

The following measurements were recognized to the most valuable in the day by day activity of a radio optimization department:
- Best server Common Pilot Channel (CPICH) carrier energy to noise density ratio collected when first accessing the network (CPICH $E_{c}/N_0$, shortly access $E_{c}/N_0$), defined in [5]
- **Propagation delay**, defined in [6]

Both measurements are reported to the RNC with the RRC Connection Requests, and can be combined in a distribution (see an example in Fig. 1) that gives important indications about the area where the cell collects subscriber traffic (not to be confused with the serving area, which could be wider due to SHO) and the quality of the coverage.

![Figure 1. Propagation delay vs. access $E_{c}/N_0$](image)

A diagram like the one shown in the figure above allows identifying:
- Coverage resurgences: in the example, the cell draws traffic between 3.5 and 7 Km, with low access $E_{c}/N_0$ values
- Unclear dominance areas close to the site, which are characterized by poor access $E_{c}/N_0$ and small values of propagation delay

Other useful information can be gathered by processing RRC Measurement Reports. The reports, triggered by particular events or sent periodically, typically contain pilot signal strength (CPICH Received Signal Code Power, shortly RSCP) and $E_{c}/N_0$ of all the cells in the active set and a subset of the monitored cells (for details, see [5]).

The comparison between the number of replacement (1c) and addition (1a) events was recognized as a good method to identify pilot polluters. In fact, a target cell that usually enters (or exits) the active set by replacement can be classified as polluter for the active set cells.

The utilization of the signal measurement quantities must take into consideration whether the measurements are event triggered or periodical. Periodical reporting can be considered as uniformly distributed in the serving area of a cell, while event triggered reports come typically from UEs located in SHO areas.

In general, $E_{c}/N_0$ and RSCP measurements are not useful when looked at one at a time. The combined $E_{c}/N_0$ vs. RSCP distribution can be used to identify:
- Polluted and interfered cells, characterized by low $E_{c}/N_0$ in good coverage areas (high RSCP)
- Cells providing coverage in indoor environment or at long distance in areas where they are the unique serving cell, characterized by good $E_{c}/N_0$ in low RSCP areas
It is worth noting that the cell characterization given by this $E_b/N_0$ vs. $RSRP$ distribution is much more significant than the one offered by a drive test, since it describes the cell behavior for both outdoor and indoor users.

Finally, Radio Link (RL) power values per service type can be collected by monitoring RRC Dedicated Measurement Reports and RRC Radio Bearer Reconfiguration messages [7]. The periodicity of dedicated report is defined by RNC data build parameters.

An example of RL power distributions for Circuit Switched (CS) voice (AMR) and video calls and Packet Switched (PS) Non Real Time (NRT) services is depicted in Fig. 2.

![Radio Link power distributions per service](image1)

**Figure 2. Radio Link power distributions per service**

The power distributions can be used to:
- Verify the impact on power utilization efficiency when modifying the RNC data build parameters of specific services
- Identify cells that use higher power compared to the average values in a reference area, in order to detect abnormalities in path loss (due to long range coverage, indoor traffic, cable losses), downlink interference or wrong parameter settings
- Obtain a semi-empirical model to forecast the evolution of the downlink power usage as a function of the traffic increase (the calculation method will be shortly described in section 3.2)

### 3. Network Performance Assessment

The metrics introduced in Section 2 will now be combined into cell behavioral profiles, which are meant to translate the knowledge of expert radio planners into objective rules.

#### 3.1. Neighbor cells assessment

The neighbor cells assessment allows providing an optimized adjacency plan based on reliable lists of missing and useless adjacencies calculated automatically.

The identification of undefined intra-frequency, inter-frequency and inter-system neighbors is based on the combination of the lists of several cells in SHO. For instance, looking at the example depicted in Fig. 3, the lack of a neighborhood definition including cells B and C can be identified by examining the RRC Measurement Reports sent by UEs in SHO with A and B when performing handovers to C.

![Missing neighbor cells identification](image2)

**Figure 3. Missing neighbor cells identification**

The classification of adjacencies is based on a cost function involving the quantity and quality measurements introduced in section 2.1.

For example, in case of intra-frequency neighbors, the following rules apply:
- Undefined cells are classified as missing neighbors (candidate for addition) if
  \[ SHOshare + ActiveSetProbability > UpperThreshold \]
- Defined neighbors are classified as redundant (candidate for removal) if
  \[ SHOshare + ActiveSetProbability < LowerThreshold \]

An example of a graphical representation of an optimized plan is shown in Fig. 4.

![Graphical representation of an optimized neighbors plan](image3)

**Figure 4. Graphical representation of an optimized neighbors plan**
The defined neighbors are joined to the source cell by a line, the addition and deletion proposals are identified with a star and a barred circle, respectively. It is important to notice that the proposed addition or deletion of any cell to the neighbor list is subjected to verification of the statistical reliability, defined by the following conditions:

- **SHOshare** and **ActiveSetProbability** calculated on day N are reliable if the number of SHO events is higher than a given threshold
- An addition or deletion proposal is validated with a p/n method: considering days N, N-1 and N-2, the proposal is valid only if the condition was satisfied in at least 2 days out of 3. This condition filters out the effects of abnormal conditions (temporary unavailability of a cell)

### 3.2. Air interface assessment

The measurements introduced in section 2.2 can be used to classify the radio behavior of a cell in terms of serving area, dominance and DL power utilization.

The serving area of a WCDMA cell is the territory where the cell collects traffic. A cell can draw traffic as single component of the active set or, for UEs in SHO, as a branch of the active set. The weight of the traffic collected by a cell due to SHO is usually measured by the **average active set size**.

The evaluation of the serving area based on propagation delay, being based on the proportion of RRC connections gathered for each distance step (as in Fig. 5), cannot account for the positioning of the traffic due to SHO, which remains unpredictable.

**Figure 5. Graphical representation of the propagation delay distribution**

Thus, in order to roughly determine the areas where UEs are simultaneously connected to other cells than the one under characterization, it is necessary to plot on a map the **SHOshare** of each neighboring cell. An example is reported in Fig. 6.

**Figure 6. Graphical representation of the SHOshare**

The second important aspect of cell behavior is dominance. According to [3], a cell has poor dominance if it is not the best server (in terms of $E_c/N_0$) in the area where it provides coverage or it has an excessive SHO area. Low dominance is diagnosed when a cell exhibits:

- Low average values of access $E_c/N_0$
- High ratio of RRC connections that are released during the access phase due to UE re-selection towards another cell
- High ratio of ISHOs triggered by low $E_c/N_0$
- High **average active set size**

Note that “low” and “high” values are in practice defined by experienced radio planners.

Low dominance might be due to pilot pollution (see section 2.2), in which case the cell is also characterized by a high percentage of replacements on the total number of SHO events. Table 1 shows the example of a cell characterized by low dominance (notice the low access $E_c/N_0$ and high **average active set size**), presented with the most likely polluters.

### Table 1. Low dominance cell and its most likely polluters

<table>
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<tr>
<th>SOURCE_TILE_ID</th>
<th>SOURCE_WCCH_ID</th>
<th>ACCESS $E_c/N_0$</th>
<th>RRC_access_fail due to cell 19-90</th>
<th>RRC_access_fail due to cell 19-90</th>
<th>Average active set size</th>
<th>Pollutant</th>
<th>Pollutant</th>
<th>Pollutant</th>
<th>Pollutant</th>
<th>Pollutant</th>
<th>Summary</th>
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<td>1.00</td>
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<td>100%</td>
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<td>1.00</td>
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</table>

Table 1 shows the example of a cell characterized by low dominance (notice the low access $E_c/N_0$ and high average active set size), presented with the most likely polluters.
The polluter weight is a cost function based on the percentage of replacements (1c) over the total number of SHO events; the Summary depends also on the reliability of the statistics of the source and target cell. Given a threshold for the Summary value, pilot polluters can be automatically recognized.

Both the problems related to the cell serving area or to low dominance can be addressed by optimizing antenna system parameters (i.e. tilt and azimuth) and data build parameter (e.g. CPICH transmission power). The radio behavior of a cell is further characterized by the DL power utilization, which can be derived from the power allocated to common channels, the average traffic per bearer and the power distributions per radio link type (introduced in section 2.2). Common channels power is usually a function of the pilot channel power and can be expressed as

\[ P_{TX, CommonChannels} = \sum_{ch} V_{ch} \cdot (P_{TX, PrimaryCPICH} - Offset_{ch}) \]

\( Offset_{ch} \) is the power offset of the common channel (namely P-SCH, S-SCH, P-CCPCH, PICH, AICH and S-CCPCH [5]) from the CPICH power \( P_{TX, PrimaryCPICH} \) and \( V_{ch} \) the activity factor of the same channel.

The average DL power utilization is given by:

\[ P_{TX, Average} = P_{TX, CommonChannels} + \sum_{r} v_{r} \cdot A_{r} \cdot P_{r, Mean} \]

where, for each bearer, \( v_{r} \) is the activity factor, \( A_{r} \) is the average traffic, and \( P_{r, Mean} \) is the mean value of the power per service. The \( P_{TX, Average} \) calculated according to the above formula for a number of cells were compared to the corresponding values given by RNC counters. Fig. 7 summarizes the results (each point identifies a cell) and demonstrates the good match between the two methods of estimating average total transmitted power.

The proposed method has the advantage of considering independently the contributions due to the traffic amount and the power utilization in the cell. This formulation, given a forecast of traffic increase, enables to evaluate the short term evolution of the power utilization of a cell and to predict the need for a capacity expansion (e.g. the introduction of a second carrier).

4. Automation of the Optimization Process

The data flow from RNC monitoring to the delivery of the information to the radio optimization department is fully automated, as shown in Fig. 8. In the proposed implementation, signaling logs are collected from RNC and transferred to a workstation; only the relevant messages are monitored in order to reduce the storage requirements. The logs are then processed to extract the counters defined in section 2. The counters can be stored in the same database dedicated to normal RNC counters, together with the optimization proposals which could be the result of SQL queries or, like the power capacity evolution, the result of specific post-processing.

Summarizing the analysis described in section 3, the following results are presented in tabular format:
- Neighbors assessment: addition and deletion of intra-frequency and inter-system adjacencies
- Low dominance cells and related pilot polluters
- Contributions to total DL transmitted power

The following information is presented on map:
- Adjacencies addition and deletion (see Fig. 4)
- Propagation delay distributions (as in Fig. 5)

The process described above is by no means autonomic, essentially because there is no closed control loop, nor learning [8]. Thus, the following additions to the process shown in Fig. 8 are necessary to obtain at least some degree of autonomicity:
- The calculation and deployment of optimized parameters must be automated, in order to close the control loop.

![Figure 7. Comparison between PtxTotal values derived using counters and from formula](image)

![Figure 8. Automation of the optimization process](image)
- The cell performance assessment process should be continuous, not triggered by human intervention
- The thresholds used in cell behavior assessment algorithms should not be set by a radio expert but, for instance, dynamically adjusted based on a statistical analysis of KPI values.

Note that the optimization loop could in practice be implemented in the RNC, by integrating the log processing needed to obtain counters and KPIs, the rules used to detect cell behavior anomalies and those to calculate new parameter values into an Autonomic Manager framework as the one described in [9].

5. Estimating the OPEX Reduction

Operators face several challenges when managing WCDMA networks, such as:
- Limitation in number of resources to support multiple network technologies (e.g. 2G and 3G)
- Inhomogeneous level of 3G competence across the organization
- Proactive management of network growth
- Complex processes and inefficient utilization of tools and resources

On the other hand, optimization of adjacencies, tilt and dominance is mandatory in order to ultimately guarantee better service availability and performance, thus significantly reducing risk of churn. Drive tests, though very expensive, are a common source of performance data. Data analysis does not always guarantee consistent results, since it depends on the skill level of the radio personnel assigned to the task.

The proposed signaling-based solution fits into Operators optimization processes replacing a number of complex steps with a simpler and almost fully automated process. The amount of savings that can be achieved is very difficult to estimate due to many variable factors such as drive test frequency and costs, man-day cost, time spent for drive test analysis and tools, impact of network optimization and quality on churn rate or stimulated revenues and so forth. Anyway, considering that the initial investments needed to deploy the signaling-based process and the corresponding maintenance fees are fully counterbalanced by the reduced number of tools/licenses Operators traditionally have to purchase for field optimization, the main savings are: 25% in drive test costs and 50% in costs deriving from data analysis.

The aforementioned benefits result in a total cost reduction, compared to the conventional optimization process, which can be approximately estimated between 30% and 40%.

6. Conclusions and future work

This paper explores only some of the measurements and corresponding assessment criteria of RNC signaling-based optimization. In fact, the analysis proposed in section 3 addresses only the basic needs of an Operator radio planning department. Starting from the same principles and platform more data can be automatically provided to radio planners.

The utilization of cell behavioral profiles allows translating the best practices applied by experienced radio planners in a common methodology, easily transferable to planning departments, improving the quality of the work by reducing the time spent in mechanically processing huge amounts of data.

Further work is needed in order to make the optimization process autonomous. An implementation of the optimization engine in the network element is in line with the solutions envisioned for future wireless access systems, like 3GPP LTE and WiMAX.

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