A Roadmap from UMTS Optimization to LTE Self-Optimization

Oriol Sallent, Jordi Pérez-Romero, Juan Sánchez-González, and Ramon Agustí,
Universitat Politècnica de Catalunya (UPC)
Miguel Ángel Díaz-Guerra, David Henche, and Daniel Paul, Telefónica

ABSTRACT

Self-Organizing Networks (SON) are currently being introduced by the 3rd Generation Partnership Project (3GPP) as part of the Long Term Evolution (LTE) system as a key driver for improving the operation of wireless networks. Given that many challenges have been identified when moving from the SON concept to practical implementation, this article claims the suitability to gain insight into the problem by taking advantage of optimization mechanisms in live Universal Mobile Telecommunications System (UMTS) networks. From that perspective, this article outlines a roadmap from actual manual optimization toward the inclusion of SON concepts in future networks. In particular, an optimization framework is developed considering different stages that include the collection of inputs from different sources (network counters, measurement reports, drive tests), the tuning parameters to achieve optimization, and the optimization procedure itself. Even though the proposed framework is presented and evaluated for convenience in a UMTS context, it is rather generic and technology-agnostic and, therefore, it can be formulated as an initial reference for LTE self-optimization use cases. The proposed framework is applied to a practical coverage optimization use case supported by data extracted from a real UMTS network in a European city, illustrating the capability to automatically identify a cell with sub-optimal coverage and to provide a solution to the problem. The extension of the case study to LTE is also analyzed. Finally, as a result of the lessons learned, the article makes a projection to the LTE context by identifying the key points to be solved for the materialization of a self-optimization procedure.

INTRODUCTION

Third-generation (3G) mobile communication systems have seen widespread deployment around the world. The uptake in High Speed Packet Access (HSPA) subscriptions, numbering well over 85 million at the start of 2009 [1], indicates that the global thirst for mobile data has just begun: broadband subscriptions are expected to reach 3.4 billion by 2014, and about 80 percent of these consumers will use mobile broadband.

Operators are doing business in an increasingly competitive environment, competing not only with other operators, but also with new players and new business models. In this context, any vision for technology evolution should encompass an overall cost-efficient end-to-end low latency proposition. By the end of 2004, 3GPP started discussions on 3G evolution toward a mobile communication system that could take the telecom industry into the 2020s. Since then, the 3GPP has been working on two approaches for 3G evolution: LTE and HSPA+. The former is being designed without backward compatibility constraints, whereas the latter will be able to add new technical features preserving Wideband Code Division Multiple Access (WCDMA) and HSPA investments.

Besides the evolution in radio technologies and network architectures, the conception of how these networks should be operated and managed is evolving as well. The envisaged high density of small sites, e.g., with the introduction of femto-cells, and the pressure to reduce costs, clearly indicate that deploying and running networks needs to be more cost-effective. SON, aiming to configure and optimize the network automatically, is seen as one of the promising areas for an operator to save operational expenditures. Indeed, it can be stated that SON will be required to make the business case for LTE more attractive. Consequently, SON has received much attention in recent years. For example, in the framework of the Next Generation Mobile Networks (NGMN) Alliance, operator use cases have been formulated for different stages [2]: planning (e.g., eNode-B power settings), deployment (e.g., transport parameter set-up), optimization (e.g., radio parameter optimization that can be capacity, coverage or performance driven), and maintenance (e.g., software upgrade). Similarly, the ICT-FP7 SOCRATES project defined a detailed use case taxonomy in [3]. 3GPP has also acknowledged the importance of SON [4]. Progress is being reflected e.g., in [5], where use cases are being developed together with required functionalities, evaluation criteria

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and expected results, impacted specifications and interfaces, etc. Similarly, the ICT-FP7 SOCRATES project is developing in deeper detail different use cases, such as cell outage [6]. Paradigms related to SON are discussed in an early paper in this area [7]. Additionally, in [8] the self-configuration of newly added eNode-Bs in LTE networks is discussed, and a self-optimization load balancing mechanism is proposed as well.

Due to its ambitious objectives, the practical realization of SON is seen as challenging, and it can be anticipated that SON will continue as a hot research topic in coming years requiring further research efforts. Some of the aspects that must be properly covered include: to find an appropriate trade-off between the performance gains and the implementation complexity (e.g., required signaling and measurements, computing resources), to ensure the convergence to a stable solution within a given timing requirement or to ensure the robustness to missing, wrong or corrupted input measurements.

The radical changes needed from current deployed networks such as Second-generation (2G) and 3G HSPA, mainly managed by centralized remote operations and maintenance (O&M) applications with intensive human intervention, to future SONs (LTE, HSPA+) undoubtedly require the definition of a clear roadmap when moving from SON's concepts to their practical implementation. The impact will be on all aspects of an operator's radio engineering department (operational procedures, O&M software tools, radio engineer's skills, etc.). In this respect, early actions enabling a smooth introduction of the "SON culture" may be highly beneficial on a long-term perspective. This article outlines a roadmap from actual manual UMTS optimization toward the futuristic objective of a self-optimized LTE.

In particular, this article first develops a UMTS optimization framework, discussing from a practical perspective the inputs available for an automatic optimization process as well as the optimization procedure itself. Even though the proposed optimization framework is presented for convenience in a UMTS context, it is rather generic and technology-agnostic and, therefore, it can be formulated as the initial reference for LTE self-optimization use cases. Second, this article formulates a UMTS coverage optimization case study, supported by data extracted from a real UMTS network in a large European city. The main objective of the proposed case study is to gain insight into the problem from a practical point of view, in order to identify and draw conclusions on the key points to be solved for the materialization of a full self-optimization procedure. Given the differences in radio access technology, we also analyze how the coverage optimization use case could be extended to LTE. In turn, we collect the lessons learned from the UMTS case study and project them into the LTE context. This is accompanied by the up-to-date status of SON in research and standardization fora, so that the motivation of this article to contribute to on-going efforts from a complementary perspective is enforced. Finally, we summarize the conclusions reached.

UMTS OPTIMIZATION FRAMEWORK

UMTS network optimization turns out to be a tricky and complex task because the target objectives in terms of coverage, capacity, and quality tend to be contradictory (e.g., capacity may be increased at the expense of coverage or quality reduction) [9]. Additionally, the number of tunable parameters in a WCDMA network is significantly higher than that of a 2G Time Division Multiple Access (TDMA)-based network. In such complex scenarios, efficient network management is needed in order to guarantee the QoS requirements to the subscribed users. In recent years, an intensive effort has been made in the field of automated optimization [10–14]. Two different phases can be distinguished in the optimization of a 3G system [15]. The first phase is RF optimization, whose objective is to guarantee the required coverage, avoiding excessive pilot pollution, cell overlap or cell overshoot by optimizing the setting of RF parameters such as pilot power, antenna down-tilt, etc. The second phase is service parameter optimization. This includes the setting of admission and congestion control thresholds, maximum downlink power per connection, events to change to compressed mode, channel switching, etc.

INPUTS FOR THE OPTIMIZATION PROCESS

In order to perform the radio optimization process, the actual network status and performance needs to be captured. Clearly, the more accurate and complete this picture is the more efficient the optimization process can be expected. In practice, the network operator can collect diverse information about the network status from different sources:

Network counters: These are measurements taken at Node-Bs and/or Radio Network Controllers (RNC), such as load levels, number of users in soft/softer handover, etc. that are transferred to the O&M module (e.g., transmitted power level can be recorded at the Node-B and forwarded to the O&M module every 15 minutes in the form of average values or statistical distributions). Typically, the manufacturer provides the operator with the software tool to manage the collection, processing (e.g., measurement averaging), and transference from network elements to O&M. The type of measurements that a given network element must be able to perform is usually defined in the standards [16–18].

Measurement reports: These are measurements taken by the mobile terminals while in an active connection and transmitted live to the RNCs (e.g., received power of the pilot channel, pilot channel energy per chip over total received power density for the serving and neighboring cells, etc.). The primary usage of these reports is as input for Radio Resource Management (RRM) algorithms, such as a handover algorithm. Nevertheless, these measurements can also be used as an input for the optimization process. In such a case, measurement reports need to be managed by a software tool, able to store and forward them to the O&M.

Drive tests: These are measurements carried out by one or several specialized terminals able

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Drive test measurements mainly illustrate the status of the downlink for the particular trajectory followed by the testing vehicle. Therefore, it is most important to specify such trajectory so that it ensures the acquisition of measurements in the areas where the real traffic is generated.

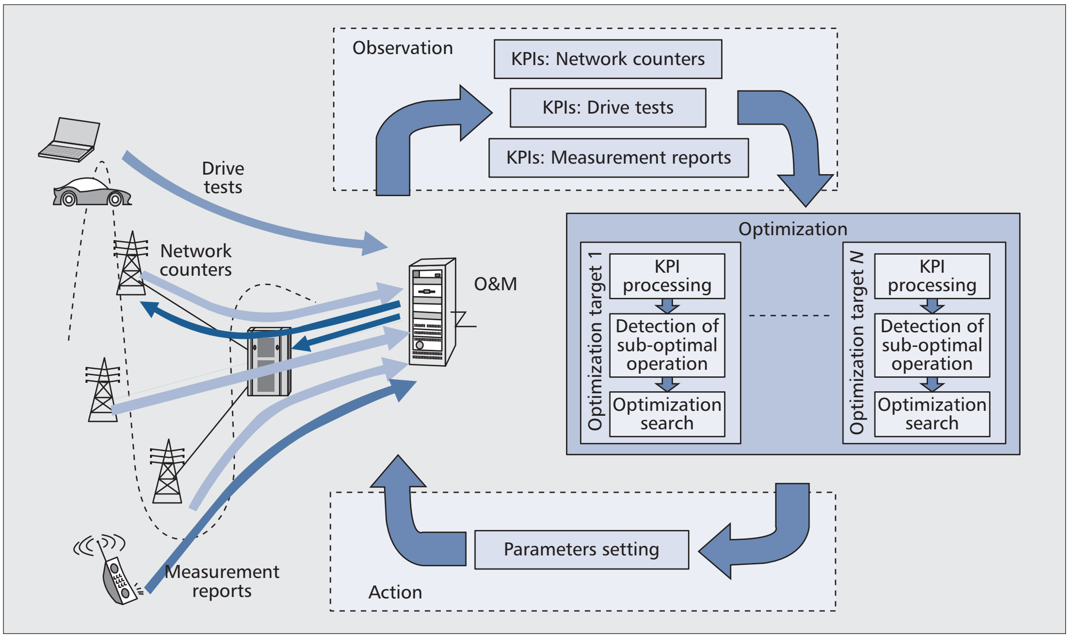

Figure 1. *Network optimization loop.*

to record a number of parameters while following a trajectory in the field. They are equipped with a Global Positioning System (GPS), so that the position where each measurement has been taken is also recorded. For example, when some misbehavior of the network is identified, radio optimization engineers can trigger a drive test over the affected area in order to obtain further information about the operating conditions. Nevertheless, drive tests can also be regularly performed as a basis of network quality control and as another input to the network optimization process. A drive test performed with a frequency scanner can also be very useful because it is able to capture true coverage predictions without the influence of the specific network configuration. This can be of particular interest in, for example, a 3G/2G heterogeneous scenario where quality problems in 3G could be automatically overcome by diverting traffic to the 2G network, thus hiding the 3G problems.

It is worth noting that network counters are able to capture mainly the behavior of the uplink, whereas measurement reports are mainly able to collect the status of the downlink. In turn, drive tests acquire similar information as measurement reports, with the additional advantage that the precise position where each measurement is taken is recorded. Drive test measurements mainly illustrate the status of the downlink for the particular trajectory followed by the testing vehicle. Therefore, it is most important to specify such trajectory so that it ensures the acquisition of measurements in the areas where the real traffic is generated.

OPTIMIZATION PROCEDURE

The overall network optimization procedure is illustrated in Fig. 1 and Fig. 2, providing the most generic view where possible inputs coming from network counters, measurement reports, and drive test are considered. The procedure acts as a loop that continuously interacts with the real network based on *observation* and *actions*.

At the observation stage, the optimization procedure collects information from the different available Key Performance Indicators (KPIs). Then the optimization procedure will contain different processes for each of the optimization targets specified based on operator policies (e.g., avoidance of coverage holes, interference reduction, reduction of overlapping between cells, etc.). For each optimization target a three-step process will be executed, consisting of:

- Processing the KPIs coming from the observation phase (e.g., combining several KPIs, obtaining statistical measurements such as averages or percentiles, etc.).
- Detecting the sub-optimal operation, i.e., that the optimization target is not properly fulfilled, based on some criteria dependent on the specific target.
- Carrying out an optimization search to find the proper parameter setting to solve the sub-optimal operation.

The final result of the optimization will be the adequate configuration of selected network parameters (e.g., antenna downtilts, pilot powers, RRM parameters configuration, etc.) affecting either the cell where the sub-optimal operation has been found and/or its neighboring cells. This change in the configuration parameter(s) turns out to be the *action* executed over the network.

The optimization process is formulated in the form of hypotheses tests against the sub-optimal operation for a number of established targets. Hypotheses are reinforced by a likelihood index that is increased every time a given condition evaluated over a certain KPI (or combination of KPIs) is met. Considering that a total of N_c conditions $c(i)$ $i = 1,\dots N_c$ are evaluated, each condition will have an associated weight α_i depending on how relevant the condition is for the optimization target under consideration.

With the degrees of freedom provided by the weight factors α_i, the value of the likelihood index F is then simply defined as a linear combination of the evaluated conditions:

$$F = \frac{\sum_{i=1}^{N_c} \alpha_i U(c(i))}{\sum_{i=1}^{N_c} \alpha_i} \qquad (1)$$

where $U(c(i))$ takes the value 1 if condition $c(i)$ is fulfilled, and 0 otherwise. As a result, F is a relative value between 0 and 1. The higher the F value is, the more likely that the target is not sufficiently optimized. The likelihood index F can be defined for every optimization target according to the specific conditions established, and the weight associated with every condition can be fixed according to the operator's strategy and policies.

Given that not necessarily all the required KPIs to detect a given sub-optimal operation may be available (e.g., measurement reports from the mobile may not be available at O&M, drive tests may not have been run for a given area, etc.), a reliability index R in the detection should be defined in accordance with how many conditions are actually evaluated with respect to the total number of potential conditions N_{tot} that would be evaluated if all KPIs were available:

$$R = \frac{\sum_{i=1}^{N_c} \alpha_i}{\sum_{i=1}^{N_{tot}} \alpha_i} \qquad (2)$$

As a final result for the detection of suboptimal operation with respect to a given target, the cell under study will be categorized as one of the following:

- If $F < F_{\min}$, it is likely that the target is optimized. Reliability of this hypothesis will be associated with the obtained value of R.
- If $F \geq F_{\min}$, the most likely hypothesis is that the target is not sufficiently optimized. In this case:
  - –If the reliability index $R \geq R_{\min}$, then the optimization search stage is triggered. In this case, if drive test measurements are available, it may be possible to identify specific geographical areas (denoted here as clusters) where the sub-optimal behavior is detected. This is done by grouping the drive test positions exhibiting the particular sub-optimal behavior based on their geographical distance.
  - –If the reliability index $R < R_{\min}$, then it is decided that there is not sufficient information about the network status to perform an automated optimization search procedure. In this case, an alarm will be triggered indicating that human intervention is required for the optimization of this target in this cell.

It is worth noting that the thresholds $F_{\min}$ and $R_{\min}$ will be set according to the operator's strategy and policies. A high value for $F_{\min}$ will tend to trigger optimization search procedures only for cases where the likelihood that sub-optimal operation exists is high. A high value for $R_{\min}$ will indicate that the operator relies on the automatic operation when many inputs from the network status are available; otherwise the operator prefers analyzing the situation with the assistance of a radio engineer expert.

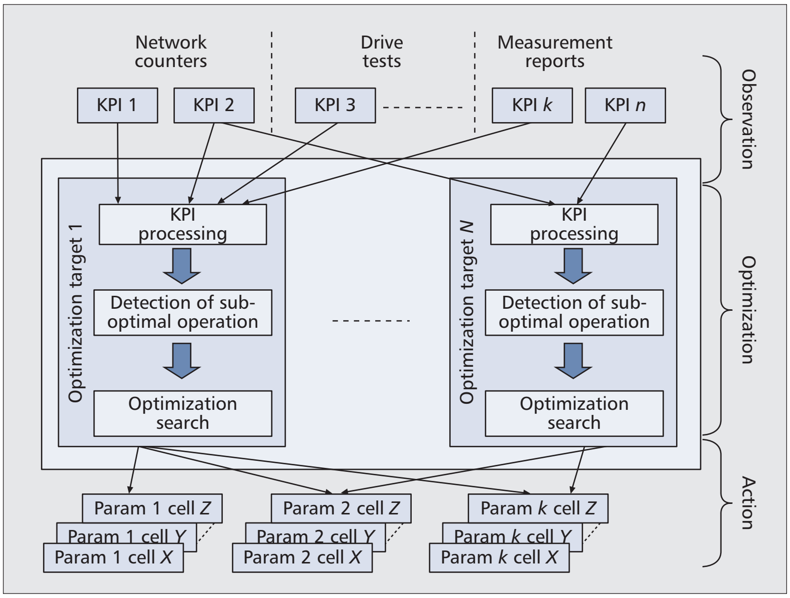

Figure 2. *Processes in the network optimization algorithm.*

In case the suboptimal operation has been detected, the role of the optimization search is to propose certain changes in the configuration parameters of one or several cells (e.g., the cell where the suboptimal operation was detected and/or its neighbors) in order to provide an optimized operation. Each target will have a number of associated parameters, which are related to the resulting performance for such target. Since a given parameter may be related to several optimization targets fixed by the operator and may also have a direct influence on other parameters, the choice of parameter and its new value must be carefully studied, requiring some degree of coordination between the optimization searches associated with different targets.

Given that parameter change on the live network is a very sensitive issue, optimization algorithms will usually require the support of a module devoted to estimate the expected impact of a given parameter change (e.g., a planning tool, a system level simulator, a software tool fed with real data measurements, etc.) prior to the modification in the live network. In practice, since the automatization of this stage may involve the integration of very diverse software tools, some human intervention may be required in the meantime.

The optimization search strategy can be based on different approaches depending on the specific target and the parameter(s) to optimize. Classical optimization methods, such as e.g., genetic algorithms, linear programming, particle swarm algorithms, etc., or other heuristic approaches, can be considered. Such methods could be adequately extended to address the problem from the multi-objective optimization perspective, jointly taking into account the dif-

Considered KPIs	Criteria/Condition	Source
RSCP (Received Signal Code Power from the CPICH channel)	$Prob(RSCP<RSCP^*)>Th_{RSCP}(\%)$	Drive Test/Measurement Report
Uplink transmission power P_T	$Prob(P_T>P_T^*)>Th_{PT}(\%)$	Drive Test/Measurement Report
Active Set and Monitored Set	The Active Set is not full ($AS < AS_{max}$) and there exists a cell in the Monitored Set that should be in Active Set.	Drive Test/Measurement Report
Number of handover attempts to GSM relative to cell load	$\frac{NumberHO\_GSM}{Cell\_throughput} > Th_{GSM}$	Network counters
Uplink RSSI (Received Signal Strength Indicator at the Node-B)	$Prob(RSSI<RSSI^*)>Th_{RSSI}(\%)$	Network counters
Statistical distribution of the propagation delay between mobiles and base station.	$Prob(Propdelay<P^*)>Th_{propdelay}(\%)$	Network counters

Network configuration parameters/Tunable parameters
Positions of the different nodes B in the network.
Antenna azimuth of the different cells.
Neighbor lists.
CPICH transmission power in the different cells.
Antenna downtilt of the different cells

Table 1. *Considered KPIs and tunable parameters.*

ferent optimization targets [19, 20]. Furthermore, learning mechanisms can also be applied at this stage.

CASE STUDY: UMTS COVERAGE OPTIMIZATION

In order to illustrate the framework presented in the previous section, the procedure for the optimization of UMTS coverage is presented. The considered scenario is shown in Fig. 6. It consists of six tri-sectorial cells in an urban area of a major European city. Each cell is identified as $Cell\_x\_y$ where x corresponds to the Node-B identifier and y is the sector of this Node-B.

Table 1 shows the KPIs that can be useful for the optimization of the UMTS coverage in a given cell, the corresponding conditions to detect suboptimal behavior, and the source from which each KPI can be obtained. As shown, these conditions are based on statistics related to power measurements, handovers, or propagation delay measurements. Some hints about the rationale to consider these specific KPIs are given in the following:

- In general, poor coverage will be associated with low values of Received Signal Code Power (RSCP) of the Common Pilot Channel (CPICH) and Received Signal Strength Indicator (RSSI) at the Node-B.
- High uplink transmitted power may indicate excessive propagation losses and, consequently, poor coverage.
- A high ratio of handovers from UMTS to Global System for Mobile communications (GSM) cells may indicate UMTS coverage problems, provided that the applied network selection strategy is such that it favors continuity over UMTS once attached to this network. Besides, coverage problems may prevent the Active Set (AS) and Monitored Set (MS) lists from being adequately updated (e.g., due to problems in the signaling procedures for adding/removing cells from the Active Set, derived from the fact that some messages can be lost due to coverage problems).
- Finally, the statistical distribution of the propagation delay of specific signals transmitted from mobiles to cell is considered to be a valuable input because it reflects the statistical distribution of mobiles-to-cell distances when connected to the cell. More specifically, in case that users tend to connect only at distances much below the planned cell coverage radius, this might reflect suboptimal coverage at the cell edge.

Table 1 also shows the configuration parameters that are needed in the suboptimal operation detection process, which in turn will usually be the tunable parameters to be considered in the optimization search stage.

The algorithm for the detection of sub-optimal coverage operation is presented in Fig. 3, making use of the conditions presented in Table 1. It is worth noting that the RSCP condition is evaluated not only for the cell under study but

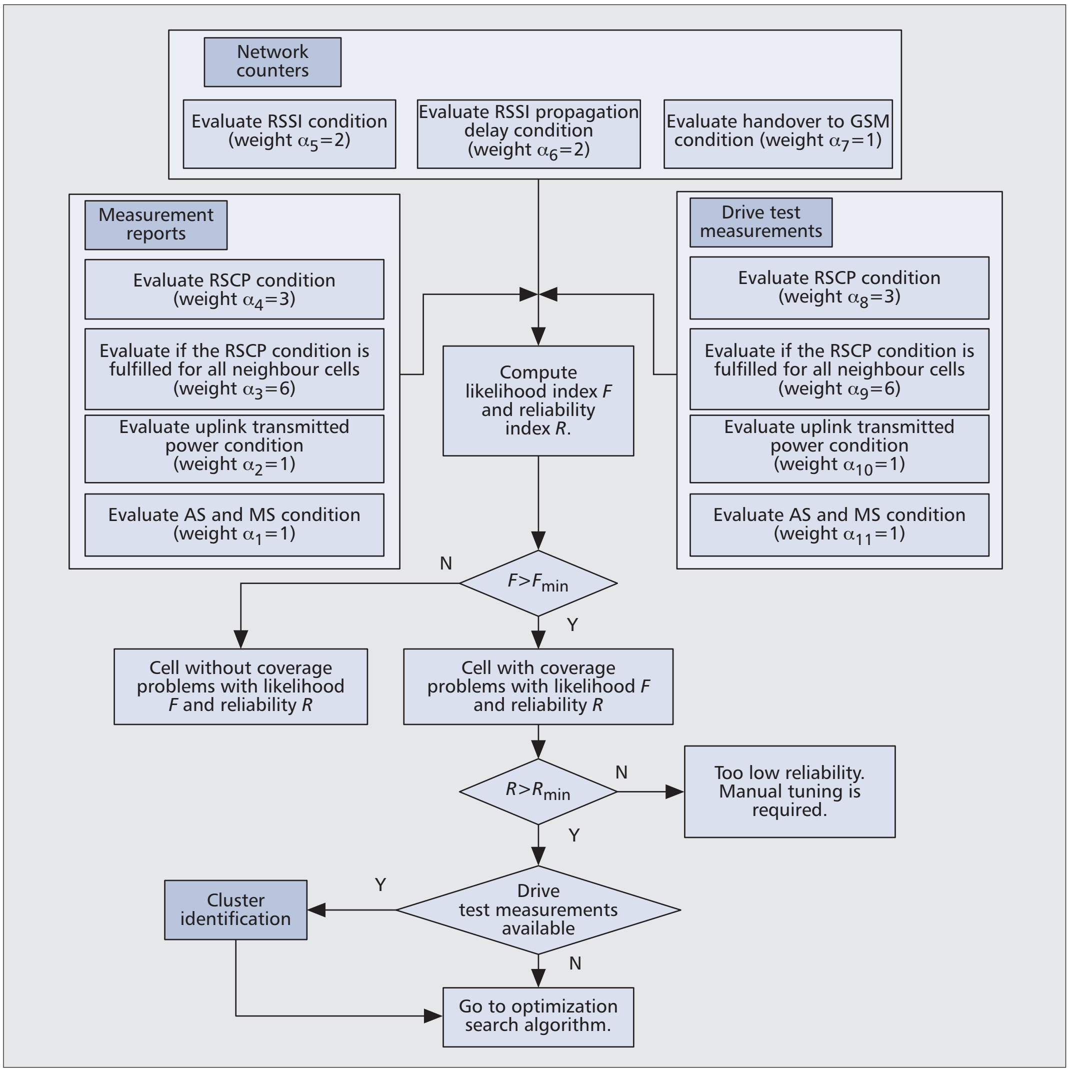

Figure 3. *Detection of sub-optimal operation algorithm.*

The statistical distribution of the propagation delay of specific signals transmitted from mobiles to cell is considered to be a valuable input because it reflects the statistical distribution of mobiles-to-cell distances when connected to the cell.

also for the neighboring cells, so as to increase the likelihood of sub-optimal coverage in case neither the cell under study nor any of its neighboring cells are detected with a high enough RSCP. According to these conditions and its corresponding weights α_i shown in Fig. 3, the algorithm determines the reliability index *R* and the likelihood index *F* in the detection of coverage problems. If the likelihood and reliability index are higher than certain thresholds (e.g., $R_{min} = 0.4$ and $F_{min} = 0.6$ are chosen in this case study), coverage problems in the cell under study are assumed and the optimization search is activated.

In order to gain some insight into the network status in the considered scenario, some examples of measurements used for the detection of sub-optimal cell coverage are presented and discussed in the following. On the one hand, Fig. 4 shows the Cumulative Distribution Function (CDF) of the RSCP for different cells when each considered cell is detected either in the active set if the mobile is in connected mode or as best server if the mobile is in idle mode. While the RSCP in *Cell_6_2* is below –85dBm for around 90 percent of the samples available in the cell, *Cell_6_1* exhibits only 10 percent below that threshold and *Cell_6_3* exhibits that almost all samples are above the threshold. Therefore, the observation of this plot may point out coverage problems within *Cell_6_2*. On the other hand, the correlation between the uplink transmitted power and the RSCP is presented in Fig. 5. A cell with coverage problems may have a high percentage of measurements with a high uplink transmitted power and a low RSCP (e.g., *Cell_6_2*). In terms of the algorithm for the detection of sub-optimal coverage, this linkage has been captured by including one condition on RSCP and another condition on the uplink transmitted power. If both are fulfilled (i.e., low RSCP in downlink and high transmitted power in uplink are observed), the likelihood index *F* that the cell is affected by coverage problems increases. On the contrary, cells like *Cell_6_3*, with low values of uplink transmitted power and high RSCP values, are not expected to have coverage problems.

In order to assess the performance of the automated coverage optimization process in this real scenario, the algorithm presented in Fig. 3 is executed. Considering the weights for each condition indicated in Fig. 3 and the definitions of likelihood index and reliability index indicated in Eqs. 1 and 2, the result obtained with the available data for *Cell_6_2* is $F = 0.93$ and $R = 0.48$. Therefore, since $F \geq F_{min} = 0.6$, the most likely hypothesis is that the coverage is not sufficiently optimized. Besides, since $R \geq R_{min} = 0.4$, the optimization search stage is triggered. Furthermore, since drive test measurements are available in this case, the algorithm is able to identify three clusters where the sub-optimal coverage is localized (the identified clusters are shown by circles in Fig. 6).

The optimization search considered here is based on readjusting the antenna downtilt of the cell under study (or some neighbors) so as to improve the coverage in the cluster locations while maintaining proper coverage in the rest of the cell. From a practical perspective, electrical tilt would be preferred, while mechanical tilt should be limited to a certain maximum in order to avoid deformation on the main radiation lobe.

The procedure makes use of the knowledge about the antenna radiation pattern of the different cells together with the measurements available from the drive tests and the information about the positions of the different clusters identified in the detection step. The procedure first considers downtilt changes for the cell where the problem was detected (*Cell 6_2* in this example). An iterative search is carried out by shifting the downtilt in steps of Δ degrees up to a maximum Δ_{max}. For each iteration and for each sample corresponding to each identified cluster an estimation of the resulting RSCP value is computed using the antenna radiation pattern. As a result, an estimation of the percentage of samples with expected RSCP above threshold RSCP* is obtained for each considered downtilt. If a downtilt providing sufficient improvement is found, then a recommendation for parameter change is drawn. Otherwise, the algorithm concludes that it is not possible to optimize the coverage of this cell through downtilting on the same cell and a solution search over neighboring cells is triggered. In that case, a similar procedure is executed by considering different downtilts in neighboring cells. The algorithm will be able to provide a recommendation about downtilt change in a neighboring cell provided that the neighbor can significantly improve the coverage over the affected clusters whilw still maintaining proper RSCP levels over its own coverage area.

Applying the optimization search algorithm in the analyzed scenario, it is found that no downtilt change on *Cell_6_2* would provide sufficient RSCP improvement over the cell. Therefore, the solution search was extended to neighboring cells. In this case, it was found that a downtilt change from 11° to 4° in *Cell_4_1* would improve the overall situation.

In order to understand the outcome of the optimization algorithm, Fig. 7 shows, on the one hand, the CDF for the RSCP from *Cell 6_2* corresponding to the samples taken along the drive test segment marked in Fig. 6. It can be clearly observed that poor coverage is provided over *Cell 6_2*, since almost 85 percent of the samples are below –88 dBm. In a closer view, measured data over the drive test (not shown in the figures for the sake of brevity) reveal that *Cell 6_2* is not detected at all in Cluster 1, while it is detected with an average value of –92 dBm in Cluster 2 and –93 dBm in Cluster 3. In turn, with respect to *Cell 4_1*, this becomes the best server along Clusters 1, 2 and 3 (which are within the theoretical coverage area from *Cell 6_2*), although it is received with very low values of RSCP, in most of the cases below -88 dBm.

Figure 7 shows, on the other hand, the CDF for the RSCP received from *Cell 4_1* along the drive test for downtilt values of 4° and 11°. Thanks to the downtilt change from 11° to 4° the probability of low RSCP values is reduced, which illustrates that RSCPs from *Cell 4_1* improve at Clusters 1, 2 and 3. This is at the expense of reducing the probability of high RSCP, although this is not impacting negatively on the coverage provided by *Cell 4_1* along its own theoretical coverage area. After the downtilt adjustment in *Cell_4_1*, the likelihood index and the reliability index for *Cell_6_2* are calculated again for the new situation. $F = 0.46$ and $R = 0.48$ are obtained. *F* is reduced because the RSCP condition for neighbor cells (Fig. 3) is not fulfilled in the resulting scenario. Given that $F < F_{min}$, the output of the algorithm is that coverage is suffi-

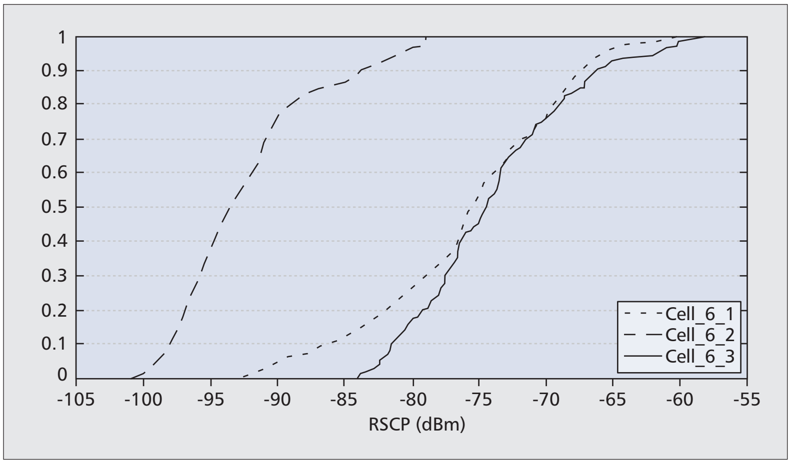

Figure 4. *Cumulative distribution function of the RSCP.*

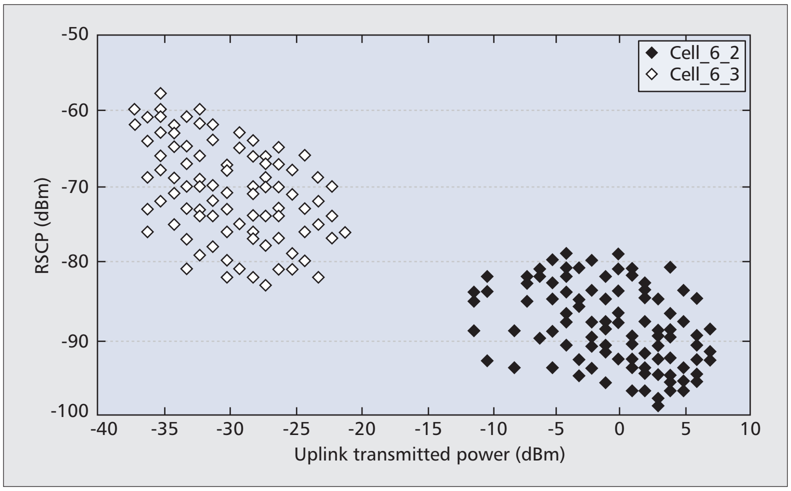

Figure 5. *Correlation between RSCP and uplink transmit power.*

ciently optimized and, therefore, the coverage problem has been solved with this action.

In conclusion, this example has shown a practical case where a cell provides poor coverage, which is eventually overcome by increasing the overlapping from a neighboring cell. Indeed, in order to verify the conclusions reached in this exercise, a closer analysis in-the-field was conducted and it was found that there were some high buildings obstructing the antenna of *Cell_6_2* in the direction of the clusters, so it was not possible to improve the coverage in those areas by acting on the downtilt of that particular cell.

EXTENSION TO LTE

In order to illustrate that the actual work on UMTS optimization can also provide valuable background for LTE, this section discusses how the coverage optimization case study presented for UMTS could be extended to the LTE case. In this way, the usefulness of the presented framework as a basis for LTE is emphasized, even though the type of optimization targets to be considered and the specific KPIs can be different as they are technology-specific. Similarly, there would be differences in terms of system architecture, so that while in UMTS many of the KPIs can be available at the RNC, in LTE most of the KPIs will be available at the eNode-Bs.

Table 2 presents the extension of the KPIs and tunable parameters from the UMTS case to the LTE case. As can be observed, the conditions to detect the sub-optimal coverage are also based on statistics related to power measurements, handovers, and propagation delay. Nevertheless, there is some specificity as indicated in the following:

- The corresponding measurement that can be equivalent to the RSCP in UMTS is the Reference Signal Received Power (RSRP), which corresponds to the measured power by the mobile terminal at the specific reference signals transmitted by the eNode-B [21].
- As for the uplink case, given that in LTE there also exists a power control scheme, the uplink transmitted power in either Physical Uplink Control Channel (PUCCH) or Physical Uplink Shared Channel (PUSCH) that can be collected through drive tests or measurement reports, can also be used to identify poor coverage situations whenever the transmit power is above some threshold, reflecting excessive propagation losses. Note also here that the RSSI in the uplink that was considered in UMTS is no longer considered in the LTE case, given that this measurement is actually not collected by the eNode-B [21].
- The condition regarding the number of handover attempts to GSM has been reformulated to also include the handovers to UMTS, to reflect that a large number of handovers to these technologies could be an indication of LTE coverage problems.
- The condition regarding the AS and MS configuration used in UMTS is no longer considered in LTE, given that no soft handover is used. Instead, the considered condition corresponds to the monitoring of the RSRP in the neighboring cells. In particular, if the best cell is not actually the serving cell, this could reflect problems in the signaling associated with the handover procedure that can be due to coverage problems.

Figure 6. *Scenario and location of the identified clusters.*

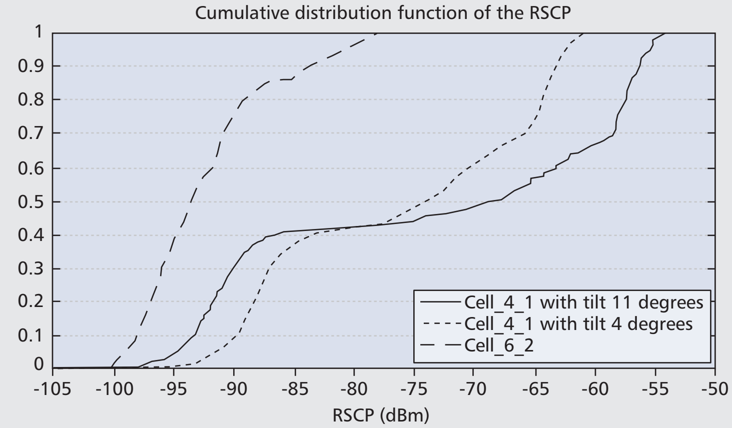

Figure 7. *CPICH RSCP before and after the downtilt correction.*

- As for the condition related to the propagation delay, it can also be used in the context of LTE. While in UMTS the estimation of this metric is implementation-dependent and could be obtained from the delays in the random access, the availability of time advance measurements in LTE makes even more straightforward the estimation of the propagation delay, with a resolution of 0.52 μs [22].

Based on the above conditions, the algorithm for the detection of sub-optimal coverage in LTE would be very similar to the one presented in Fig. 3 for UMTS with the corresponding modifications in accordance with the KPIs and condi-

Considered KPIs	Criteria/Condition	Source
RSRP (Reference Signal Received Power) of serving cell	$Prob(RSRP<RSRP^*)>Th_{RSRP}(\%)$	Drive Test/Measurement Report
Uplink transmission power P_T	$Prob(P_T>P_T^*)>Th_{PT}(\%)$	Drive Test/Measurement Report
RSRP of neighboring cells	The best cell is not the serving cell	Drive Test/Measurement Report
Number of handover attempts to GSM/UMTS relative to cell load	$\frac{NumberHO\_GSM + NumberHO\_UMTS}{Cell\_throughput} > Th_{HO}$	Network counters
Statistical distribution of the propagation delay between mobiles and base station.	$Prob(Propdelay<P^*)>Th_{propdelay}(\%)$	Network counters
Network configuration parameters/Tunable parameters		
Positions of the different e-nodes B in the network.		
Antenna azimuth of the different cells.		
Neighbor lists.		
Transmit power in the different cells.		
Antenna downtilt of the different cells		

Table 2. *Considered KPIs and tunable parameters for the LTE case.*

tions from Table 2. Similarly, the concepts of reliability *R* and likelihood index *F* would also be applicable, although perhaps with different values depending on the weights to be set for each condition.

INSIGHTS FOR LTE SELF-OPTIMIZATION

SON is introduced as part of the 3GPP LTE as a key driver for improving O&M. SON concepts are introduced in LTE starting from the first release of the technology (Release 8), and expanding in scope with subsequent releases. The progressive inclusion of standardized SON features certainly reflects the expected LTE network evolution stages as a function of time. For example, Release 8 includes functions covering different aspects of the eNode-B self-configuration (automatic inventory, automatic software download, automatic neighbor relation, automatic physical Cell Identifier (Cell ID) assignment [23]). The objective of self-configuration is to provide "plug and play" functionality in the planning, integration, and configuration of new eNode-Bs. In turn, Release 9 will provide SON functionalities addressing optimization. This phased approach, targeting automated optimization for more maturing network stages, seems fairly reasonable given the ambitious objectives of a full SON. Some of the considered use cases in Release 9 are:

- Mobility robustness optimization, encompassing the automated optimization of parameters affecting active mode and idle mode handovers to ensure good end-user quality and performance.
- Load balancing optimization, in order to intelligently spread user traffic across the system's radio resources as necessary in order to provide quality end-user experience and performance, while simultaneously optimizing system capacity.
- Coverage and capacity optimization, which is related to the case study presented earlier. While the goal is the same regardless of radio technology, the specific algorithms and parameters vary with technology. This has been illustrated earlier, which has outlined a possible solution.

Release 9 also includes elements to increase energy savings, UE reporting functionality to minimize the amount of drive tests, etc. Nevertheless, it is worth emphasizing that SON-related functionalities will continue to expand through the subsequent releases of the LTE standard.

In this context, where a full LTE-SON can be set as the skyline ultimate objective, it is important to devise a roadmap starting from actual commonly-used manual-based UMTS optimization. The practical experience gained so far, as reflected in this article, has brought to some observations, sometimes over-sought when tackling the problem from a theoretical/simulation perspective, as well as to the identification of some key open points to be tackled in this evolutionary process toward LTE-SON. Similarly, lessons learned can also be of help and provide a complementary and reinforcing approach, particularly at the time that LTE-SON is still taking full shape and while it cannot benefit from live network experiences. In this respect, it is worth mentioning:

- Given that the practical implementation of SON concepts puts strong requirements on the capabilities offered by O&M tools and impacts all aspects of an operator's radio engineering department, early actions enabling a smooth introduction of the "SON culture" may be highly beneficial on a long-term perspective.
- The optimization framework presented earlier can be considered as a reference starting point for LTE, given that the main principles highlighted are technology-independent. In particular, the different sources to acquire the network status, the network optimization loop and the process in the network optimization algorithm are, indeed, of rather general applicability.
- Related to SON architectures, guiding principles and operational procedures, again the framework proposed in this article, which has been derived from a practical perspective, can be useful for the consolidation of SON in the framework of LTE [24].
- Given the uncertainty about the network status, outputs from SON algorithms require associated likelihood/reliability indicators. Therefore, this approach as presented in Section II with *F* and *R* parameters tightly coupled with the detection of sub-optimal behavior could also be applicable in the LTE context.
- Given that changing the network configuration/parameterization is a critical action from the operator's perspective, the automated optimization procedure is likely to be introduced in a step-by-step approach. While automatic sub-optimal behavior detection mechanisms can be considered mature enough (as reflected in the presented UMTS case study), the automatization of optimization search and parameter change is seen at this stage, and even for UMTS networks, far from mature. The confidence in such automatic procedures as required by the operator needs to be significantly enhanced, as discussed in the points below.
- Optimization search procedures need to be specifically developed for each possible parameter. Criteria to anticipate the most suitable parameter to cope with a given sub-optimal operation need to be established.
- Supporting tools and/or models for the optimization search stage require further research. The estimation of the impact of a given parameter change on the live network as part of the optimization procedure is a critical point.
- The ultimate view of SON, where the joint self-optimization of several targets is performed, may raise complex interactions. The influence of the execution of a stand-alone optimization target on the rest of the targets needs to be investigated.
- In the best case, SON will be able to automatically detect a sub-optimal operation and provide a corrective action. However, in some cases the SON algorithm may fail in detecting the problem or may be unable to provide a recommendation for a corrective action.
- Besides, there are incipient market solutions for UMTS optimization that allow KPIs' delocalization. This promising feature, which is expected to mature in a LTE context, may reduce the need for drive tests in the future and pave the way for a full self-optimization framework.

CONCLUSION AND FUTURE WORK

SON is introduced as part of the 3GPP LTE as a key driver for improving O&M. However, given that many challenges are identified when moving from the SON concept to practical implementation, this article has claimed the suitability to gain insight into the problem by taking advantage of optimization mechanisms in live UMTS networks.

The article has developed an optimization framework considering different stages: inputs from different possible sources (network counters, measurement reports, drive tests), tuning parameters to achieve optimization and the optimization procedure itself (including KPIs processing, sub-optimal operation detection for a given target and optimization search). The optimization process has been formulated in the form of hypotheses tests against the sub-optimal operation for a number of established targets. Hypotheses are reinforced by likelihood and reliability indexes, so that the number and relevance of diverse KPIs with respect to the considered target can be weighted.

The optimization framework has been applied to a UMTS coverage optimization use case in a large European city. The algorithm has allowed the automated identification of a cell with sub-optimal coverage and provided a solution to better optimize its operation. The extension to LTE has been analyzed, identifying a number of specificities to be considered due to technology change.

Finally, this article has provided some insight for LTE self-optimization. On one side, it has been discussed that the presented optimization framework could also be taken as a reference in the LTE context. On the other side, lessons learned from the UMTS case study have enabled the identification of a number of key issues to be solved in the evolutionary path toward LTE-SON. Besides, it has been highlighted that a step-by-step introduction of SON can be sound in practice, implementing self-detection with manual self-optimization in a first stage and progressively moving toward automatization of the optimization search.

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BIOGRAPHIES

ORIOL SALLENT (sallent@tsc.upc.edu) is Associate Professor at the Universitat Politècnica de Catalunya. His research interests are in the field of mobile communication systems, especially radio resource and spectrum management for cognitive heterogeneous wireless networks. He has published more than 150 papers in international journals and conferences. He has participated in several research projects of the 5th 6th and 7th Framework Program of the European Commission and served as a consultant for a number of private companies.

JORDI PÉREZ-ROMERO is currently associate professor at the Dept. of Signal Theory and Communications of the Universitat Politècnica de Catalunya (UPC) in Barcelona, Spain. He received the Telecommunications Engineering degree and the Ph.D. from the same university in 1997 and 2001. His research interests are in the field of mobile communication systems, especially packet radio techniques, radio resource and QoS management, heterogeneous wireless networks and cognitive networks. He has been involved in different European Projects as well as in projects for private companies. He has published papers in international journals and conferences and has co-authored one book on mobile communications. He is associate editor of IEEE Vehicular Technology Magazine and Eurasip Journal on Wireless Communications Networks.

JUAN SANCHEZ-GONZALEZ received the Engineer of Telecommunications and Ph.D. degrees from the Universitat Politècnica de Catalunya (UPC), Barcelona, in 2002 and 2007, respectively. He is currently assistant professor in the department of Signal Theory and Communications in UPC. He has participated in projects funded by the European Union as well as in projects for private companies. His research interests include radio resource and QoS management for wireless communication networks, optimization of cellular systems and cognitive networks.

RAMON AGUSTI received the Engineer of Telecommunications degree from the Universidad Politécnica de Madrid, Spain, in 1973, and the Ph.D. degree from the Universitat Politècnica de Catalunya (UPC), Spain, 1978. He became Full Professor of the Department of Signal Theory and Communications (UPC) in 1987. After graduation he was working in the field of digital communications with particular emphasis on transmission and development aspects in fixed digital radio, both radio relay and mobile communications. For the last fifteen years he has been mainly concerned with aspects related to radio resource management in mobile communications. He has published about two hundred papers in these areas and co-authored three books. He participated in the European program COST 231 and in the COST 259 as Spanish representative delegate. He has also participated in the RACE, ACTS and IST European research programs as well as in many private and public funded projects. He received the Catalonia Engineer of the year prize in 1998 and the Narcis Monturiol Medal issued by the Government of Catalonia in 2002 for his research contributions to the mobile communications field. He is a Member of the Spanish Engineering Academy.

MIGUEL ÁNGEL DIAZ-GUERRA received the Telecommunications Engineering degree from the Universidad Politécnica de Madrid, Spain, in 1992. In 1994 he joined Telefónica. He has been working in Radio Planning and Radio Optimization during 16 years. He has collaborated in different research projects with University. He has participated in international projects inside Telefónica Group in Latin-American and Europe. He currently is Access Network Engineering Manager.

DAVID HENCHE received the Telecommunications Engineering degree from the Universidad Politécnica de Cataluña, Spain, in 1993. In 1995 he joined Telefónica, where he currently is Radio Access Network Engineer working in the planning and deploying area. His main interests are in the field of internal and external interference detection and removal to increase network performance, and optimal deployment of mobile networks for current and new future data services.

DANIEL PAUL received the Telecommunications Engineering degree from the Universidad Politécnica de Madrid, Spain, in 1989. In 2001 he joined Telefónica, where he currently is Access Network Engineering Director. Prior to that, he was with Motorola, where he has been working from 1990 participating in the initial development of the GSM system and participating in the GSM deployment in a number of operators in Europe. His main interests are in the field of new techniques of radio access network optimization and the optimal deployment of MBB networks adjusted for the new future data services.