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Cloud-Based Implementation of a SON Radio Resources Planning System for Mobile Networks and Integration in SaaS Metric

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ABSTRACT In mobile network deployments of growing size, the optimum and fast planning of radio resources are a key task. Cloud services enable efficient and scalable implementation of procedures and algorithms. In this paper, a proof of concept implementation of a cloud-based network planning work pattern using Amazon Web Services (AWS) is presented, containing new and efficient radio resource planning algorithms for 3G, 4G and 5G systems. It extracts configuration and performance data from the network, enabling to accurately estimate cells coverage, identify neighboring cells and optimally plan scrambling codes (SCs) and physical cell identity (PCI) in 3G and 4G/5G networks, respectively. This implementation was integrated and is available in the commercial Metric Software-as-a-Service (SaaS) monitoring and planning tool. The cloud-based planning system is demonstrated in various canonical and realistic Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE) scenarios, and compared to an algorithm previously used by Metric. For a small LTE realistic scenario consisting of 9 sites and 23 cells, it takes less than 0.6 seconds to perform the planning. For an UMTS realistic scenario with 12 484 unplanned cells, the planning is efficiently achieved, taking less than 8 seconds, and guaranteeing no collisions between first order neighboring cells. The proposed concept is proved, as this system, capable of automatically planning 3/4/5G realistic networks of multi-vendor equipment, makes Metric more attractive to the market.

INDEX TERMS Cloud computing, coverage estimation, proof-of-concept, optimized planning tool, metric platform, radio resources, SON, cellular networks, SaaS implementation, efficient algorithms.

I. INTRODUCTION

In the recent years, the world has been witnessing an exponential growth of mobile data usage [1]. This requires constant evolution and densification of mobile networks operating in a wireless environment shared by thousands of cells and mobile devices. Cellular systems have evolved rapidly, from 3G Universal Mobile Telecommunications System (UMTS), to 4G Long Term Evolution (LTE) [2] and emerging 5G [3], to provide a larger variety of services with growing capacity and latency requirements. The planning of these cellular networks is critical. Although 3G, 4G and 5G are different in their approaches to share the wireless medium, all must plan their radio resources efficiently to guarantee communication between users and their covering cells without interference from neighboring cells. This is challenging, as radio resources are scarce and must be reused.

These cellular networks became so large, dense and heterogeneous that require automatic planning, optimization and maintenance procedures, following the Self-Organizing Network (SON) paradigm [4]. The gathering and processing of such large quantities of information coming from these

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networks may be enabled by cloud services, which offer scalable and elastic storage, processing and networking resources on-demand. In [5]–[9], it is demonstrated that the estimation of coverage within a SON context may gain from the use of cloud services. The large variety of different configuration parameters and Key Performance Indicators (KPIs) from cells using equipment from various manufacturers may be normalized thanks to a cloud-based infrastructure enabling their congregation and combination with large amounts of Drive Tests (DTs) to build accurate estimations of cell coverage. Another example is given in [10], [11] where the identification of neighboring cells is performed thanks to a cloud-based work pattern.

In the planning of cellular resources, an example of this trend in supporting SON by cloud services is presented in [12], [13], a recent investigation proposing an automatic and efficient planning strategy for large cellular Global System for Mobile Communications (GSM) deployments. Although a well-known technology with more than 30 years, commercial available planning tools like Metric Software-as-a-Service (SaaS) [14] are adopting such methodologies. They evidence large gains in the implementation of these algorithms and work patterns in the planning of large and dense deployments which require efficient allocation of resources. Similarly, in [15] and [16], first thoughts are drafted of a cloud work-pattern for an UMTS planning algorithm. Although preliminary researches, it evidences that gains may be reached by such an approach.

A motivation for this work is the OptiNet-5G project (Planning and Optimization Framework of 5G Heterogeneous Networks in a Cloud Environment) [17], an R&D project aiming to bring improvements to the Metric platform of Multivision, a commercially available monitoring, planning and optimization tool for radio access networks. Metric intends to ease the work of a network engineer by making it more autonomous. Within OptiNet, besides researching, implementing and integrating novel mechanisms for planning and optimization of radio resources, is intended to implement this tool as a SaaS, recurring to cloud-services of Amazon Web Services (AWS) [18], which offers reliable, scalable, and inexpensive cloud computing services. As this system does not require human interaction, it shall represent a novel SON implementation, in which the cloud services enable the automatic network monitoring, planning, optimization and healing in a serverless way.

In this paper, novel cellular planning and optimization algorithms for UMTS (3G), LTE (4G) and 5G networks are proposed for the automatic and efficient configuration of radio resources. Their detailed algorithmic description is presented. To enable their integration within a single heterogeneous networks' system, an architecture is proposed using a novel SON cloud-based work pattern, for a correct planning and maintenance of the cellular network. It is possible to self-plan an entire network, optimally allocating resources to each of them. On the other side, it enables to self-heal cells suffering from interference, performing the self-optimization of their resources as well of neighboring ones. This work also presents novelties related to the Network Function Virtualization paradigms. It is a cloud-based system that interacts with Operation and Support Systems (OSS) of various manufacturers and systems, congregating all information in a virtualized monitoring, planning and optimization infrastructure, decoupling the software implementation of these functions from the underlying hardware [19]. The implementation using AWS cloud-services is detailed, highlighting the benefits of SaaS in terms of scalability, elasticity, on-demand and security to the planning of these systems. It is capable of aggregating configuration and KPI data from OSS of various systems and manufacturers and provide an automatic and efficient cellular planning. The performance of this system is compared to a commercially available algorithm, highlighting the benefits on efficiency and scalability. Finally, the integration of this entire work-pattern in the extended Metric SaaS is demonstrated, where the benefits for network operators are clear in the ease of usability of such algorithms and rapid and optimized results. All these algorithms have been integrated and are currently available as features in the commercially available Metric SaaS tool.

The remaining paper is structured as follows. Section II presents State of the Art, such as the definition of network resources and services and tools used, as well as related work. Section III addresses the network monitoring and planning pattern followed. Section IV details the implementation of the system in the AWS and integration in Metric. Section V presents several UMTS and LTE canonical and realistic scenarios and Section VI evaluates the performance of the proposed algorithms and implementation. Finally, main conclusions are presented in Section VII.

II. STATE OF THE ART

A. MOBILE NETWORKS' RADIO RESOURCES

Mobile networks technologies, such as the ones focused in this paper (UMTS, LTE and 5G), share the wireless medium, requiring adequate planning of radio resources to guarantee interference free operation of cells. A site designates a location where various cells are co-located, each oriented to a specific direction and operating in a specific frequency band. To cover a given service area, multiple sites are needed, resources requiring to be adequately allocated to avoid interference. In this section a discussion of these resources is presented, for which planning algorithms are posteriorly proposed

1) UMTS RADIO RESOURCES

UMTS is a system that operates in 5MHz radio channels [20]. UTRA Absolute Radio Frequency Channel Number (UARFCN) is a unique number given to each radio channel within the frequency bands used by the UMTS UTRA. The UARFCN can be used to calculate the carrier frequency. UMTS uses wideband code division multiple access (W-CDMA) mechanism, where scrambling codes (SCs) are

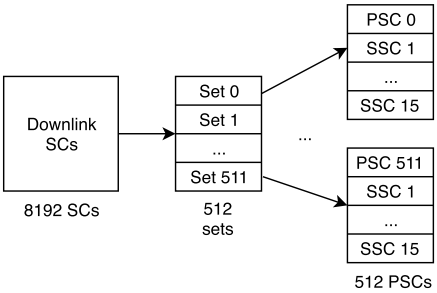


FIGURE 1. **SCs set division.**

used to separate Mobile Stations (MSs) or cells among them. As can be seen in Figure 1, there are 8192 possible SCs. In the downlink (DL), these are divided into 512 sets, each with 16 SCs. The first SC of each set is defined as primary scrambling code (PSC) and the 15 others are secondary scrambling codes (SSC) [21]. Each cell must have an assigned PSC, existing 512 available PSCs to plan the network. By making an efficient allocation of SCs to cells, interference between cells is minimized, cell search time is reduced and synchronization process too [22].

As only the PSC is required for planning, this will always be referred in the remaining text as SC. In this paper, the focus is the planning of the DL SCs, as these are the ones that require careful planning. Since in this case the number of SCs is very limited, it is normal in urban environments to have to reuse SCs, so it is important to establish a reliable neighborhood, so that it is possible to avoid interference between cells.

2) LTE RADIO RESOURCES

In LTE [23], similarly to UMTS, the carrier frequency is designated by E-UTRA Absolute Radio Frequency Channel Number (EARFCN), uniquely identifying the LTE band and carrier frequency. It uses Orthogonal Frequency Division Multiplex (OFDM). In LTE, there are three different ways to identify cells: the E-UTRAN Cell Identity (ECI); the E-UTRAN Cell Global Identifier (ECGI), with the purpose to identify a cell anywhere in the world; the physical cell identifier (PCI), responsible to distinguish a cell from its neighbors. PCI is a fundamental parameter for the correct operation of an LTE radio network.

The PCI is a code number with values between 0 and 503 [23] and, as in the SCs, it is used in the process of scrambling, in order to minimize, as much as possible, the interference between neighboring cells by, for example, making the identification of cells during the handover [24]. The automatic configuration of PCIs, as well as the detection of new neighboring cells, are a key part of the objectives proposed by 3GPP to implement SON [25]. The PCI value can be deduced from the combination of the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS). The first has its value between 0 and 2, and the second between 0 and 167, which gives 504 possible combinations, as shown in Equation 1:

$$PCI = PSS + 3SSS \tag{1}$$

As there is a limited number of PCI values, PCIs must be reused in the network. Therefore, due to its reusability, PCI cannot be seen as an unique identifier, for that purpose exists the ECGI. The reason why PCI is used instead of the ECGI is its complexity and time-consuming processing of its detection and decoding. As the SCs did in UMTS, the main function of PCIs is to separate Base Stations (BSs) that transmit in the same frequency within the LTE system [26]. Despite having similar functions for identifying BSs, the planning of PCIs is more complex than the planning of SCs, as these are associated variables that should not also be the same as closed neighbors.

The Cell Specific Reference Signal (CRS) position is influenced by the PCI used on each cell [27]. Therefore, it is important to know this position when planning the network cells' PCIs to avoid collisions and possible losses in quality of service.

In order to avoid collisions in Reference Signal (RS), two neighboring cells should follow as much as possible the following rules:

- **mod3 rule:** In DL, for an interval of 3 PCIs, when using 2 or 4 antenna ports, there will be a collision in CRS position. Therefore, for adjacent cells, the frequency shift value, should be different:

$$v_{shift,i} = PCI_i \text{ mod } 3 \tag{2}$$

- **mod6 rule:** This rule is applied the same way as the first, although it is used when only one antenna port is utilized. This way, for an interval of six PCIs, there will be an RS collision to be avoided between neighbors:

$$v_{shift,i} = PCI_i \text{ mod } 6 \tag{3}$$

- **mod30 rule:** In uplink, for each 30 PCIs, the RS pattern is the same:

$$v_{shift,i} = PCI_i \text{ mod } 30 \tag{4}$$

  This happens because the Physical Uplink Shared Channel (PUSCH) transports the Demodulation Reference Signal (DMRS) and this is built having basis in the Zadoff-Chu sequences, which are divided in group of 30, existing 30 different base sequences that can be used. These sequences should differ between neighbors.

The calculation of the Physical Control Format Indicator Channel (PCFICH) is also dependent on the PCI value [24]. This is a relevant channel, if the MS is not able to correctly decode PCFICH, there will be other channels that cannot be decoded. The PCFICH sequence is mapped into four Resource Elements Groups (REGs). In order to perform a rigorous mapping, each REG has the following calculation:

- $\bar{k}$:

$$\bar{k} = \frac{N_{SC}^{RB}}{2} \cdot (N^{PCI} \cdot mod\ 2\ N_{RB}^{DL}) \tag{5}$$

- REG (0):

$$k_0 = \overline{k} \tag{6}$$

- REG (1):

$$k_1 = \overline{k} + \lfloor \frac{N_{RB}^{DL}}{2} \rfloor \cdot \frac{N_{sc}^{RB}}{2} \tag{7}$$

- REG (2):

$$k_2 = \overline{k} + \lfloor \frac{2N_{RB}^{DL}}{2} \rfloor \cdot \frac{N_{sc}^{RB}}{2} \tag{8}$$

- REG (3):

$$k_3 = \overline{k} + \lfloor \frac{3N_{RB}^{DL}}{2} \rfloor \cdot \frac{N_{sc}^{RB}}{2} \tag{9}$$

From Equations 6, 7, 8, 9, the values from each REG are extracted. The REG values, which compose the PCFICH, should be different between close neighbors.

3) 5G RADIO RESOURCES

LTE and 5G may be very well compared when it comes to the planning of resources, more concretely the planning of PCIs [28]. The PCI value for 5G can also be deduced using Equation (1), although for 5G the value for SSS varies between 0 and 335, meaning that there are 1007 PCIs available, 503 more than LTE.

The planning rules for 5G extend the ones of LTE with an extra rule for mod4:

- **mod4 rule:** This rule is based on the sub-carrier positions of DMRS for Physical Broadcast Channel (PBCH). The sub-carriers are directly allocated to DMRS, making use of MOD4 computation, meaning that every 4 PCIs there will be an interference between the DMRS of the PCIs, which should be avoided when performing the planning of PCIs for 5G networks:

$$v_{shift,i} = PCI_i \bmod 4 \tag{10}$$

B. CLOUD SERVICES

Cloud computing offers reliable, pay-per-use and scalable storage, processing and networking services. This type of service provides scalability, in order to quickly adapt to the needs of the client, enhanced collaboration with the help of shared storage and reliability. There are many cloud services providers such as Google Cloud [29], Microsoft Azure [30] and AWS [18] provide different types of services.

Widely used in information systems, this paradigm has been also adopted by more demanding systems such as telecommunication networks. This work proposes a solution that presents a platform for the control and management of cloud-based network resources.

C. SELF-ORGANIZING NETWORKS

The Telecommunications industry is becoming more complex as new features are introduced in the networks, making it necessary to ease the planning, monitoring and optimization of the network. It is in this context that SONs appear, as this aims to provide autonomy to the network, i.e., without human intervention. The main goals of SONs are to facilitate the day-to-day job of a Telecommunications Engineer, as the processes are autonomous, bringing numerous benefits to the operators [31]. There are four main functions in the SONs context:

- self-planning, so that when a new BS is added to the network, the necessary definitions are selected;
- self-deployment that processes the data from the Self-Planning and makes the adequate installation of the node and validates it;
- self-healing represents preventive actions to prevent network problems and helps keeping the network operational;
- self-optimization uses the data gathered from the user's devices and autonomously performs the required adjustments to the network settings.

In this work, not only self-planning is addressed but also self-healing, as when the network is performing poorly, it proposes its planning in the affected zones [32].

D. CELLULAR PLANNING TOOLS

There are a wide variety of tools for planning network resources. Atoll allows the optimization of the network as well as its design, it is a multi-technology platform and is owned by Forsk [33]. Using this tool, there are predictions and live network data that can be used to assist the network planning or optimization. ASSET [34], property of TEOCO, is a radio planning tool that provides Radio Frequency coverage, capacity and also neighbor planning for cellular networks. Capesso [35], which is also owned by TEOCO, is an automatic cell planning tool that provides predictions and DT data to provide a good source for optimization. Although ASSET and Capesso are helpful in the process of planning and optimizing the network, these only provide a specific type of service. Huawei owns the GENEX U-Net [36], which is a radio planning tool that eases the planning of SCs. Although it is an advantageous tool to use, it requires manual configuration of various definitions of the network, as the minimum reuse distance (to plan neighbors) and other limitations that the network might have. The need of manually configure values, both in Atoll and Huawei's tool, brings errors and a high time spent.

Metric [14], owned by Multivision, is a SaaS SON solution for telecommunications networks. It is based in a pay-per-use and one-to-many model by the contracted costumers, based on one set of data definitions and common code. This service has the main advantage of being delivered over the web. Metric works with various technologies (2G, 3G and 4G) and vendors (e.g., Ericsson, Huawei, ZTE) being a multi-technology service and multi-data sources, all together in one environment. This platform does not allow PCI planning and the SC planning algorithm only considers the distance between the antennas, being the results achieved imprecise.

There are several algorithms for the planning of the network available in the literature. In [37], the algorithm is capable of allocating SCs by detecting collisions in two distinct forms: using the reuse distance to find neighbors and by avoiding the N^{th} tier neighbor SCs clashes. In the case this algorithm finds a collision, it assigns a new SC to that BS. This is an effective way to allocate SCs, although, this algorithm assigns random SCs to the cells, which in urban areas can cause errors. In [38], proposes two types of SCs planning, through graph coloring and by cluster reuse. This is an interesting approach, although, this method showed that depending on the network characteristics, sometimes it is not able to plan SCs.

The problems presented with planning algorithms and the difficult setup of planning tools were the motivation for this work, which has as main contributions:

- Creation and implementation of a cloud-based AWS network planning work pattern;
- Use of real data, which increases the efficiency of the work pattern implemented;
- Use of cloud services in order to improve, the processing, storage, and distribution of the work pattern;
- Improvement of the commercial tool Metric, giving it capabilities to control son networks.

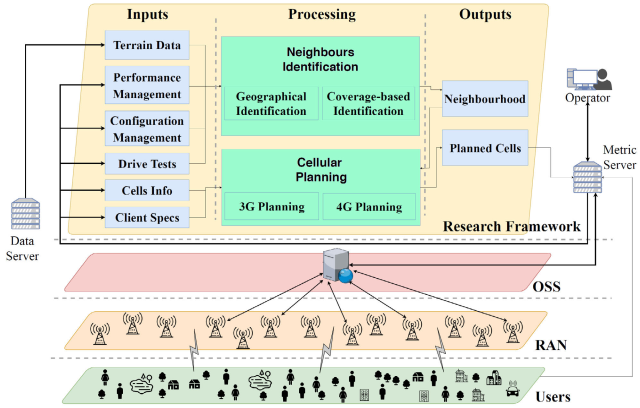


FIGURE 2. Network planning work pattern, following the SON paradigm.

III. NETWORK PLANNING PATTERN

A. ARCHITECTURE OVERVIEW

An architectural framework that supports the new planning algorithms is presented. Although the structure followed is nearly similar, there are a few key differences in the planning of UMTS SCs and LTE and 5G's PCIs. The architectural framework, represented in Figure 2, is composed of four distinct layers. Users, through its MSs, exchange traffic with the covering cells of the Radio Access Network (RAN), forwarded to the core network. Above the RAN, there is a control layer, where the OSS allows to configure and monitor network elements. On top of this layer lies the proposed research framework. A specific set of inputs are extracted by the Metric Server from the OSS, as well as from other sources. The algorithms of the neighbor's identification module provide as output a list of neighbors of the cells to be planned. This list, together with cells information and client specifications, are used by the cellular planning module to identify of the optimal resources to allocate to each planned cell. In the following sections, the modules presented in the research framework depicted in Figure 2 are detailed.

B. INPUTS

The required inputs and its description for the planning of radio resources (for UMTS and LTE/5G) are:

- **Terrain Data**: This input has two different providers. From the OpenTopography API [39] terrain morphology (elevation) is requested, for the area under consideration. Next, it is necessary to add information about height of buildings that may exist in each area. This information is requested through the Overpass API, that gathers data from OpenStreetMap [40]. This allows to create a realistic propagation environment;
- **Configuration Management**: specifications of each antenna, such as its model, height and azimuth;
- **Performance Management**: Information of the network performance, such as cell reach;
- **Drive Tests**: data related to DTs is stored directly in Metric. Considering a certain area, the DTs are used to make the calibration of the propagation model;
- **Cells' information**: this is a file that has information about each cell of the network, including its name, site it belongs to, position (latitude and longitude) and, depending on the system, UARFCN and used SC (for UMTS), and EARFCN and used PCI (for LTE/5G). It also includes the list of sites to be planned;
- **Client specifications**: these identify the reference UARFCN/EARFCN frequencies and the strategy for SC/PCI allocation among cells to plan.

C. NEIGHBORS IDENTIFICATION

1) GEOGRAPHICAL IDENTIFICATION OF NEIGHBORS ALGORITHM

This algorithm labels as $1^{st}/2^{nd}$ order neighbor cells the ones that are within a range of d_{1st_neigb} and d_{2nd_neigb} (by default 35 and 70 km, respectively), as depicted in Figure 3. For each cell to plan (so-called base cell), 1^{st} and 2^{nd} order neighbors lists must be identified.

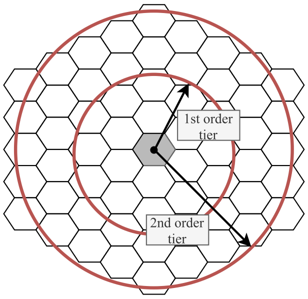


FIGURE 3. Neighborhood tiers.

First, distances from the base-cell to the remaining cells of the network are calculated. Having information of coordinates of each cell, through the Haversine formula [8], with Expressions 1, 2 and 3, it is possible to calculate the distance, d, between two cells as follows:

$$a = \operatorname{sen}^2\left(\frac{\Delta\phi}{2}\right) + \operatorname{sen}(\phi_1)\cdot\cos(\phi_2)\cdot\operatorname{sen}^2\left(\frac{\Delta\lambda}{2}\right) \tag{11}$$

$$c = 2\cdot\operatorname{arctan2}\left(\sqrt{a}, \sqrt{1-a}\right) \tag{12}$$

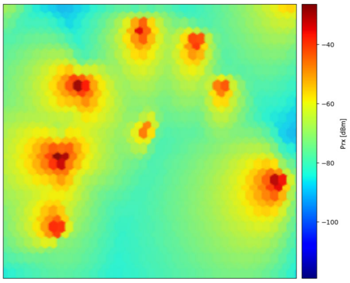
$$d = R\cdot c \tag{13}$$

where ϕ and λ are the cells' latitude and longitude, R is the Earth radius.

It is then possible to identify the cells within d_{1st_neigb} and d_{2nd_neigb} ranges, and label them as 1^{st} and 2^{nd} order neighbors, registering, for each neighbor, its distance and used SC/PC. The algorithm divides the neighbors by frequency, making it easier to plan the resources afterwards. So a site that transmits on two distinct frequencies has two different sets of neighbors, one for each UARFCN/EARFCN.

2) COVERAGE-BASED IDENTIFICATION OF NEIGHBORS ALGORITHM

The second algorithm for identification of neighbors is coverage-based. The module used for the identification of neighbors, by estimation of cell coverage, is based on the automatically calibrated standard propagation model [8]. This processing module, as can be seen in Figure 2, needs several inputs: terrain data; cells' performance and configuration management information and DTs, and antennas information (like radiation pattern). As output it provides, for a given antenna, a geo-located pixel grid where each pixel indicates the antenna's received signal level.



```
{
"Base_Cell":
        ["pixelCount", 10000 ],
        ["Neighbour1", 7500],
        ["Neighbour2", 5100],
        ["Neighbour3", 4020]
}
```

FIGURE 4. Superposition of cells' grids, indicating the number of pixels covered by a given base-cell and subset covered by surrounding neighbors.

From the propagation grid of each cell, neighboring and interfering cells, represented in Figure 4, are analyzed. Using a developed algorithm [11], the list of neighbors is established for each base-cell, as identified in Figure 4. Two interfering cells are any two cells in which each others signals reach the same location (pixel). However, two interfering cells are not necessarily neighbors. For two cells to be considered neighbors, they have to be interfering and have a received signal level, P_{rx}, higher than −120 dBm in the same pixel. A count is also made of the number of pixels in which the cells interfere, as identified in the right side of Figure 4, in order to classify the degree of neighborhood. For example, if a cell covers 10000 pixels and the neighboring one covers 7500 pixels with a power higher than −120 dBm, then it has a 75% a degree of neighborhood.

1^{st} order neighbors are those that interfere directly with a base cell with a power intensity higher than −120 dBm, and 2^{nd} order neighbors are the neighbors of the base cell's 1^{st} order neighbors. This way, a precise and effective neighborhood is established for each base-cell, in order to allow a correct re-utilization of resources of the network.

D. CELLULAR PLANNING

In order to make the correct planning of resources of an identified set of cells, a list of neighbors of each cell to plan is received from the neighbors identification module, as well as cells' information and client specifications, both imported from the Metric Server. The modules for the planning of UMTS and LTE/5G resources are presented in the following sections.

1) UMTS PLANNING ALGORITHM

An UMTS network deployment may operate in one or more UARFCN frequencies, having sites with multiple cells operating in different frequencies and SCs. In this module, we propose an algorithm capable of delivering an easy, effective and fast assignment of SCs to a set of cells that operate at different frequencies. This type of action is necessary in an existing network, for example, for the deployment of a new cell or a whole site, or to mitigate problems of interference. As input, the geographical identification of neighbors algorithm, presented in Section III-C1, is used to obtain the 1^{st} and 2^{nd} order neighbors lists of each unplanned cell, together with the associated distances.

In the developed algorithm, there are two rules that are followed, in order to make a correct allocation of resources. The main rule is that two 1^{st} order neighbors cannot share the same SC. The second rule, consists on controlling the confusions, so it also tries to avoid that the SC of one cell is used by its 2^{nd} order neighbors. In order to make a rigorous evaluation, metrics are defined, including the number of collisions of each cell with its 1^{st} order neighbors (this number should be zero) and the number of collisions and distance to 2^{nd} order neighbors. Collisions with 2^{nd} order neighbors should always be avoided, although, in urban areas this rule may not be always applicable, so the algorithm assigns the SC used by the farthest 2^{nd} order neighbor.

The steps of the proposed algorithm are detailed below:

1) **Definition of SCs' sets**: SCs sets are built following client specifications, for different numbers of cells per site. These sets may be composed of consecutive SCs (e.g., 2, 3, 4 for a 3 cells' site) or discrete (e.g., 10, 18 and 26), SCs always having values between 0 and 511.

2) **Grouping cells per frequency**: cells using the same UARFCN frequency are grouped. For each group, an independent SC planning shall be done. One site can actually have cells that use distinct UARFCNs.
3) **Definition of unavailable SCs**: for each base-cell, 1^{st} order neighbors' SCs are labeled as unavailable.
4) **SCs allocation**: SCs are allocated to the group of unplanned cells of each operating UARFCN (starting from the reference UARFCN indicated by the client specifications). There are two possible situations, when allocating SCs to cells:
    a) The most desirable situation is when it is possible to assign a set of SCs that is not being used by any of the 1^{st} and 2^{nd} order neighbors of the base-cells. In this case, collisions of any kind are prevented. This may happen usually in rural areas.
    b) The most realistic situation, and the one that we offer a solution, is where SCs must be reused between 2^{nd} order neighbors. This happens in urban areas, where the density of cells is much higher, all SCs being used by 1^{st} order neighbors. Once again, the SCs used by 1^{st} order neighbors are always to be avoided by the base-cell. In this situation, we assign the SC that is farther away from the cell, minimizing the interference. In an extreme case, the algorithm finds the most farther away 1^{st} order neighbor, to reuse its SC. This type of situation where it is necessary to find the best possible group of SCs, is detailed in Algorithm 1.

Algorithm 1 Find the Best Possible Group of SCs for Site

Input: *SCsMap*, hashmap where key is group and value is the list of SCs of that group, *cellsToPlan*, an arraylist of the cells to plan

Output: -

```
procedure findLessBadGroup(scramblingCodesMap, cellsToPlan)
    $groupsDist \leftarrow hashmap()$                ▷ Empty hashmap
    for $group$ in $SCsMap$ do
        if $group.size = cellsToPlan.size$ then
            for $sc$ in $group$ do
                if $cellsToPlan.distanceToSCs$ contains $sc$ & $cellsToPlan.usedSCByFirstOrder$ not contains $sc$ then
                    for $scAux$ in $distanceToSCs$ do
                        $dist = distanceToSCs.scAux$
                        if $dist < groupsDist.group$ then
                            $groupsDist.group = dist$
                        else
                            $groupsDist += (group, dist);$
    $entry \leftarrow int$
    $maxDist \leftarrow int$
    for $gr$ in $groupsDist$ do
        if $groupsDist.gr > maxDist$ then
            $maxDist = groupsDist.gr;$
            $entry = gr;$
    if $entry$ not null then
        $groupToUse = SCsMap.entry$
        $assignGroup(cellsToPlan, groupToUse)$
```

2) LTE/5G PLANNING ALGORITHM

The main goal of the PCI planning module is to deliver an easy, fast and effective algorithm to allocate PCIs to a set of cells. In this case, the neighbors are evaluated using the coverage-based identification of neighbors algorithm, presented in Section III-C2. For the unplanned sites, all neighbors in the network are analyzed. The interference to each of the neighbors is calculated, allowing to know which are the most and less interfering ones, allowing to know the geographical co-localization percentage of the base cell with its neighbors. This is a critical step to make the calculation of PCIs' interference. Here, neighbors are those who interfere directly with the base cell. Knowing the interference between sites it is possible to make a robust planning of resources. It has the format as represented in Figure 4.

The steps for allocation of PCIs in LTE/5G are detailed below:

1) **PCIs distribution calculation:** This module is similar to the one used in the SCs planning, although it calculates the used distribution of PCIs (consecutive or distributed), with values between 0 and 503 for LTE and 0 and 1007 for 5G.
2) **Cells' grouping per frequency:** The planning of PCIs is also performed by frequency, so the LTE network should also be divided per UARFCNs. Just like in UMTS, each site may have cells using different frequencies.
3) **PCIs interference calculation:** For each cell, the interference to each of the 504 PCIs is calculated. This calculation is made based on the interference to the set of neighbors of the base cell. The higher the interference to one neighbor, the higher the interference to the PCI it uses will be. If one cell has different neighbors using the same PCI, the interference to that PCI is cumulative. The calculation of the PCI interference depends on various values. This process is explained in Algorithm 2.
4) **PCIs allocation:** When planning PCIs there are no separate situations, as when using levels of interference, it is possible to know the interference that each PCI will cause on a specific cell. Being that the allocation of PCIs is made per site, it is necessary to make the calculation of the interference that each PCI will cause to the whole site, always depending on the neighbors. As the reference EARFCN is planned, the others will follow, depending on the client specifications. In the case of 5G planning there is the need to add the mod4 rule to the algorithm.

Algorithm 2 PCI Interference Calculation for LTE

Input: *cellsToPlan*, arraylist of cells to be planned, *pcisUsedByNeighs*, a JSON containing the PCI used by each neighbor

Output: *interferencePerPCI*, hashmap containing the interference for each PCI for each of the cells to plan

```
procedure establishPCIsInterference($cellsToPlan$, $pcisUsedByNeighs$)
    for $pci$ in $pciList$ do
        $mod3 = calculateMOD3(pci)$
        $mod6 = calculateMOD6(pci)$
        $mod30 = calculateMOD30(pci)$
        $pcfich = calculatePCFICH(pci, cellsToPlan.cellBandwidth)$
        $interfrLevel = 0$
        for $pciNeigh$ in $pcisUsedByNeighs$ do
            $pciInfo = pcisUsedByNeighs.pciNeigh$
            $numberOfCollisions = 0$
            if $mod3 = pciNeigh.mod3$ then $numberOfCollisions + 1$
            if $mod6 = pciNeigh.mod6$ then $numberOfCollisions + 1$
            if $mod30 = pciNeigh.mod30$ then $numberOfCollisions + 1$
            if $pcfich = pciNeigh.pcfich$ then $numberOfCollisions + 1$
            $interferenceLevel += (numberOfCollisions*0.25) * interfrToNeigh$
        $interfrPerPCI.put(pci, interfrLevel)$
    return $interfrPerPCI$
```

E. OUTPUTS

For both the SCs' and PCIs' planning, the main output is the resources allocated to each cell, i.e., the SC allocated to each cell in UMTS networks and for LTE/5G networks, the PCI of each cell. The final outputs of the planning process are the planned cells information, the modified cells file (with the updated SCs/PCIs for each cell) and collisions information, allowing to know if there were any problems with the network planning.

F. EVALUATION METRICS

Metrics are used to evaluate the quality of the radio resources planning:

1) For UMTS networks, the number of collisions to 1^{st} and 2^{nd} order neighbors.
2) For LTE/5G networks, the number of collisions is calculated to interfering cells.
3) The computation time is also taken into account. Any computation time higher than one minute (except when planning an entire network) is considered excessive, as this also bring higher costs.

A percentage of collisions is calculated, allowing to perceive the level of interference in the network.

IV. IMPLEMENTATION AND INTEGRATION

A. WORK PATTERN

A work pattern is proposed to implement the monitoring, planning and optimization of cellular network resources. In the context of *utility computing*, AWS services are used, enabling the interaction with the cellular network's OSS. Each processing module has its needed information in a storage service (input) and also provides information for other processing modules (output). The work pattern implemented using the AWS is depicted in Figure 5, following the SON paradigm.

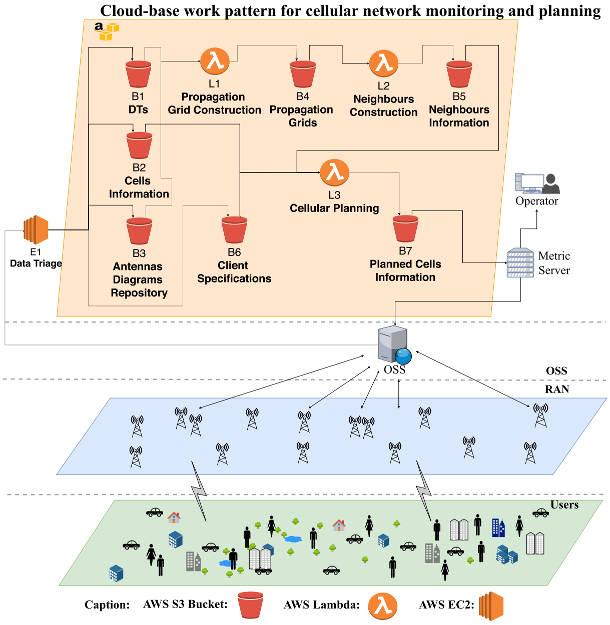


FIGURE 5. Cloud-based work pattern of the implementation of the proposed planning framework for UMTS/LTE/5G networks.

The proposed work pattern is built by combining various AWS services: an Amazon Elastic Compute Cloud (AWS EC2) service is responsible for providing computing capacity; three Amazon Lambdas are used for serverless computation; and 7 Amazon Simple Storage Services (AWS S3) for data storage. In Figure 5 the AWS E2C, AWS Lambdas, and AWS S3 are denoted by (E), (L), and (B), respectively. Their usage and combination is described next:

- **E1 - Data Triage**: This is used to process the raw data from the OSS. This allows to allocate the data to the adequate *S3* buckets;
- **B1 - DTs:** All the data related with DTs is stored in this bucket in JSON format, allowing for fast access. The DTs data are uploaded by the telecommunications operators;
- **B2 - Cells Information:** This bucket contains information about every deployed cell in the network. This data is in TSV format;
- **B3 - Antennas Diagrams Repository:** In this bucket, not only antennas diagrams (in MSI format) but also

specifications and configurations are stored in JSON format;

- **L1 - Propagation Grid Construction:** The coverage estimation of each cell is performed in this Lambda, allowing to build propagation grids for each of them. This Lambda needs the info stored in **B1**, **B2** and **B3**. It stores the output in **B4**; Each time there is a data refresh in **B1**, a new coverage estimation is performed, triggering the SON planning system;
- **B4 - Propagation Grids:** The propagation grids of each cell provided by **L1** are stored in this bucket, in JSON format;
- **L2 - NEIGHBORS Construction:** In this Lambda, neighbors are estimated. In the case of UMTS cells or when the needed data is not available, the Geographical Identification of NEIGHBORS algorithm is used. For planning LTE or 5G resources, the Coverage-based Identification of NEIGHBORS algorithm is used. This step of the process collects the necessary data from **B4** and stores its output in **B5**;
- **B5 - NEIGHBORS Information:** This bucket contains the neighbors information for each cell computed by **L2**, in JSON format;
- **B6 - Client Specifications:** All client specifications are stored in this bucket. This data is represented in a TSV file;
- **L3 - Cellular Planning:** This Lambda performs the required cellular planning of radio resources: SCs for UMTS networks, and PCIs for LTE and 5G ones. In order to properly work, **L3** collects info from **B2**, **B5** and **B6**, storing the output in **B7**;
- **B7 - Planned Cells Information:** The final planning of the network radio resources, for each of the unplanned cell, is stored in this bucket. The data is in JSON format, allowing its easy and fast access.

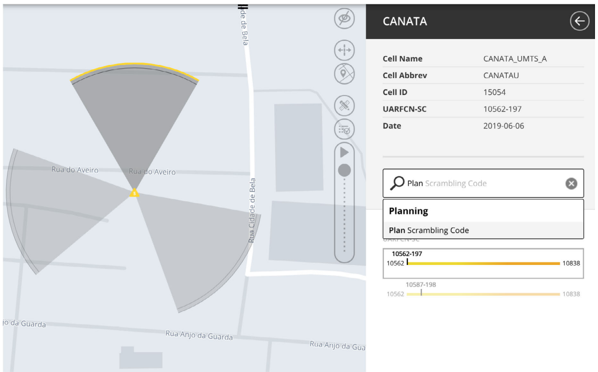
This is a serverless implementation, where the cloud provider (AWS) runs the processes, and dynamically manages the allocation of computation and storage resources. The programming language used to implement the algorithms is Java [41].

B. INTEGRATION IN METRIC

The described implementation was integrated in Metric SaaS. In this way, the network planning engineer is able to launch, with Metric and from a remote device, the cellular planning service for a network or a set of sites, triggering the developed self-planning and self-optimization mechanisms. The presented system starts by processing various data about the network, including traffic, antennas characteristics and terrain data. Being that the antennas already have their fixed location, the system starts to process which are the optimal resources to use in each cell, knowing its interference with neighboring cells. In the case of an initial planning for an entire network, this system, in the SON context, is located in the self-planning part. In the case of being an optimization to the current network, it is located in the self-optimization part. However, it is also possible to be part self-healing, as Metric constantly monitors the network, providing feedback to the operator in the form of scripts that can run to change the network configuration. In case of finding interference between neighboring cell's resources, it is possible for Metric to perform an automatic re-planning of this cells. It is important to notice that Metric integrates various procedures for the measurement of the network performance, such as KPIs, as network availability, call drop percentage, interference between resources and DTs.

The UMTS and LTE Planning Algorithms are both integrated in Metric, being that the interface to the algorithmic planning of resources is the AWS. Metric does not yet support 5G, so this algorithm is not yet integrated. This integration is a new Metric SON feature, which did not previously exist. This feature allows the operator to perform a fast and efficient radio resources planning. This work pattern does not require repeated manual configurations of the planning specifications, because Metric has this information stored in AWS.

Giving the example of planning the SCs of a specified cell or a group of cells, the user only has to select the cell and type "Plan Scrambling Code" in the text box, triggering the work pattern. The option to plan the SC of the CANATA cell is clearly demonstrated in Figure 6, making it easier and quicker for the user to perform the network planning, which is not possible in most planning tools.



CANATA

Cell Name	CANATA_UMTS_A
Cell Abbrev	CANATAU
Cell ID	15054
UARFCN-SC	10562-197
Date	2019-06-06

FIGURE 6. UMTS planning interface in Metric.

Although Metric does not have yet the capability to directly make network changes on the configuration level, these can be exported as vendor specific scripts, making it possible for the operator to run directly to enforce the changes in the network. These configuration scripts, provided to the operators, are secure in their entire process, since the data is collected, processed, and stored by AWS.

V. EVALUATION SCENARIOS

Three scenarios are defined for evaluation of the proposed algorithms and discussion of the implementation.

A. CANONICAL UMTS SCENARIO

A canonical UMTS scenario is defined, allowing to evaluate the proposed planning system and the correctness of its

TABLE 1. List of available SCs groups of two cells.

Group	SCs	Group	SCs
1	(0, 8)	5	(22, 30)
2	(2, 10)	6	(16, 24)
3	(8, 16)	7	(14, 22)
4	(19, 27)	8	(24, 32)

implementation. As input for the cellular planning algorithm, Figure 5, a scenario needs cells information (position, operating UARFCN and SC, if planned), neighbors information (for each site, sets of 1^{st} and 2^{nd} order neighbors and distances) and client specifications (reference UARFCN, SC allocation strategy and Frequency Interval), detailed below.

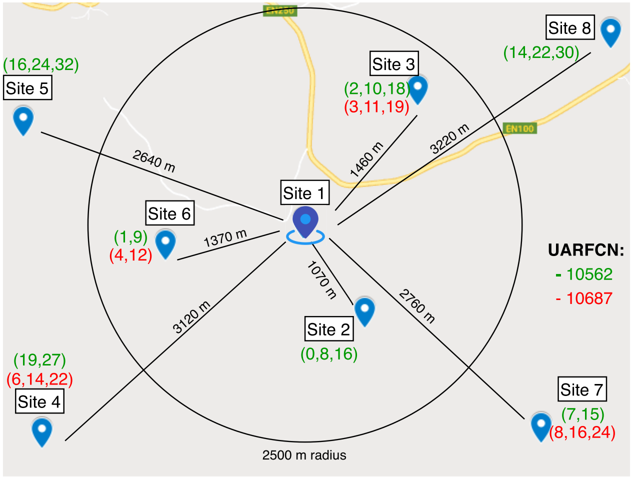


FIGURE 7. Layout of the canonical UMTS scenario.

The scenario is depicted in Figure 7, consisting of 8 sites with multiple cells each, 33 cells in total. Two distinct UARFCN frequencies are available, 10562 and 10687. All sites except Site 1 (S1) have their cells with allocated SCs. Some sites operate in two frequencies (S1, S3, S4, S6, S7) while others only in one (S2, S5 and S8). For each site, the operating SCs are identified by the colored numbers next to each site, red for UARFCN 10687 SCs and green for 10562 ones. The unplanned site S1 has 4 cells, 2 working on each of the UARFCNs. In order to ease the demonstration, d_{1st_neigb} is 2500 m.

In terms of client specifications, the reference UARFCN is 10562, being the first one to be planned. The SCs' distribution in a cell is discrete, spaced by 8 and the Frequency Interval is 1.

In order to force the algorithm to reuse SCs and find the best possible solution, the list of available SCs groups was reduced and specially selected, as listed in Table 1. It can be seen that each group has SCs spaced by 8, as specified by the client. If a group of SCs unused by 1^{st} order neighbors of S1 was available, the algorithm would immediately choose it, being a simple solution. In the configuration of the available groups, this possibility was removed.

As the reference UARFCN is 10562, this is the first one to be planned. For UARFCN 10687, the group to be chosen should follow the Frequency Interval of 1. For example, if in a cell the reference UARFCN uses group 1, UARFCN 10687 will try to use group 2. If, due to neighbors interference, it is not possible to use group 2, it finds the best one available.

B. REALISTIC UMTS SCENARIO

An UMTS scenario from an existing operator using Metric is considered. It's the entire network of a country, containing 3 719 sites and 12 484 cells, which operate in up to 5 distinct frequencies. All the cells have their SCs unplanned. In this case, all the 512 SCs are available for planning (depending on the neighbors). The client specifications are similar to the canonical scenario. In Figure 8 is depicted a snapshot of the scenario, extracted from Metric.

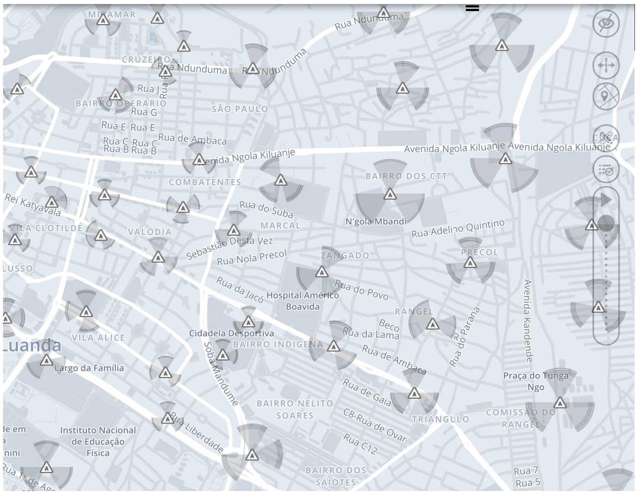


FIGURE 8. Visualization in metric of the realistic UMTS scenario.

C. LTE REALISTIC SCENARIO

A small realistic LTE scenario is also considered, from an operator using Metric. The scenario layout may be observed in Figure 9, consisting of 9 sites and 23 cells. A single EARFCN frequency is used. The PCIs allocated for this cluster are in the range of 1 to 19. In this case, we intend to plan the PCIs of Site 1 (S1), represented in blue, which has 3 cells. All PCIs are already in use by the neighbors of this site, identified under each site number.

VI. RESULTS AND DISCUSSION

A. CANONICAL UMTS SCENARIO

The UMTS canonical scenario, depicted in Figure 7, is used to discuss the steps of the algorithm detailed in Section-III-D1 in the planning of a site, as detailed next:

1) **Definition os SCs' sets:** In this case, the SCs distribution is discrete (spaced by 8), specified in the client specifications file. If, this is not specified, the

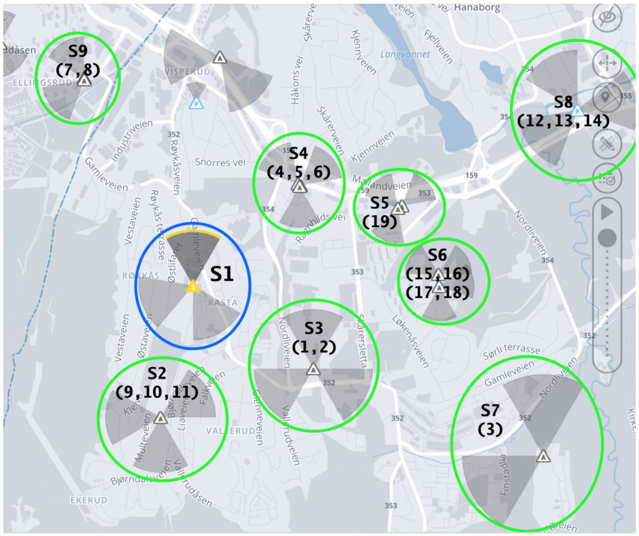


FIGURE 9. Realistic LTE scenario visualized in metric.

algorithm analyzes a random site, in order to obtain this information.

2) **Cells grouping by frequency:** Here, the analysis of cells frequency in each site is performed, allowing to build sub-networks to ease the planning.
   a) UARFCN 10562: This sub-network consists on all the sites of the scenario (S1, S2, S3, S4, S5, S6, S7 and S8).
   b) UARFCN 10687: This only contains S1, S3, S4, S6 and S7, as S2, S5 and S8 do not transmit in this frequency.

3) **NEIGHBORS analysis:** Here for each of the sub-networks, an analysis of the unplanned site S1 neighbors is made (which can be easily followed by analyzing Figure 7):
   a) UARFCN 10562: The system identifies S2, S3 and S6 as 1^{st} order neighbors of S1, as these are within the radius of d_{1st_neigb}, corresponding to 2500 meters. As d_{2nd_neigb} is not specified, it automatically assumes to be $2d_{first\_neigb} = 5000$ meters. Thus, S4, S5, S7 and S8 are 2^{nd} order neighbors of S1.
   b) UARFCN 10687: Following the same methodology as for UARFCN 10562, here the 1^{st} order neighbors of S1 are identified as S3 and S6, being that S2 is excluded. The system identifies S4 and S7 as 2^{nd} order neighbors of S1 (S5 and S8 are excluded).

4) **Definition of unavailable SCs:** The SCs used by 1^{st} order neighbors are marked as unavailable, therefore from Table 1, the groups marked as unavailable for each UARFCN are:
   a) UARFCN 10562: SCs groups 1 (SCs 0 and 8 are used by S2), 2 (SCs 2 and 10 used by S3), 3 (SCs 8 and 16 used by S2) and 6 (SC 16 used by S2) cannot be used to plan this frequency of S1. Therefore, the available groups are 4, 5, 7 and 8.
   b) UARFCN 10687: The only unavailable group for this frequency is group 4.

5) **SCs allocation:** All SC groups have SCs used within the 1^{st} or 2^{nd} order neighbors, so there is no SC available without collisions. It is necessary to find the SCs groups with less collisions and interference to neighbors, namely:
   a) UARFCN 10562: A SCs group must be found, of SCs not used by 1^{st} order neighbors, and with lowest collisions. From Table 1, it can be seen that the groups without SCs used by 1^{st} order neighbors are group 4 (of SCs 14 and 22), group 5 (22, 30), group 7 (19, 27) and group 8 (24, 32). From the 2^{nd} order neighbors sites, the most distant of S1 is site S8. Thus, the chosen group shall have SCs among the ones used on that site, SCs 14, 22 and 30 (minimizing collisions). Group 4 (14, 22) and 5 (22, 30) are available, group 4 being chosen for reference frequency UARFCN 10562 as S5, which is closer than S8, uses the SC 30.
   b) UARFCN 10687: As the frequency interval is assumed as 1 (given as input), for UARFCN 10687 the algorithm tries to use the group immediately after group 4, which is group 5 (22, 30). The algorithm makes a verification if any of the SCs on that group are used by the 1^{st} order neighbors of S1 on 10687. If it finds that any of the SCs are already used, it discards the group and finds the best option. In this case, none of the SCs are used by any of the 1^{st} order neighbors, being that only SC 22 is used by the farthest 2^{nd} order neighbor, S4. Therefore, this group can be used and is the chosen one for this UARFCN.

Resuming, for the unplanned site S1, for the reference UARFCN (10562), the SCs group used is group 4 (SCs 14 and 22) and for UARFCN 10687, the group immediately next to the one used on the reference UARFCN is used, that is, group 5 (SCs 22 and 30). This planning does not present collisions with 1^{st} order neighbors and presents 3 collisions with 2^{nd} order neighbors, which were supposed to happen. This scenario demonstrates on the one hand that the algorithm is capable of performing efficient SC planning for a scenario with multiple frequencies, and on other hand, the planning considering neighboring cells, guarantees suitable mobility, both for geographically neighboring cells and for cells working at different frequencies.

B. REALISTIC UMTS SCENARIO AND COMPARISON WITH METRIC PLANNING TOOL

Regarding the realistic scenario, composed of 12 484 unplanned cells, after running the proposed algorithm, none of them remained unplanned, showing that the algorithm is robust. None of the planned cells has collisions with

1^{st} order neighbors, evidencing the efficiency of the proposed algorithm. It takes less than 8 seconds to plan the network, revealing the speed and robustness with which any client is able to quickly and efficiently replan his network. To have a notion of complexity, in dense urban areas, within a radius of 15 km over 5000 cells might be available, many overlapping. With such an algorithm, this becomes an easy task.

The proposed UMTS planning algorithm outperforms the SQL-based implementation, previously developed and used by Metric, which, for the same scenario, requires heavy computation of Metric servers, taking 30 minutes to achieve poorer results for the same scenario.

The robustness of the system, depends on the data that serves as input to the algorithms. Still, in the daily operation of a network there are always situations of missing data. However, the implemented algorithm makes a preliminary validation of the available data, preventing the existence of errors during the planning process. In terms of scalability, by using the AWS cloud services, which are elastic, it is guaranteed that the processing is performed adequatly for any size of the network.

The speed of network planning (8 seconds to plan 12 484 unplanned cells) is possible thanks to the implemented work pattern using AWS high performing micro-processing services (Lambdas), which only exist when there is a need to perform processing, subsequently releasing those resources that can be used for other processing, being on-demand processing. When the cloud services are not used, the resources are limited, making the processing capacity inefficient. The gains of using the developed cloud-based implementation are evident. This is a major feature that provides the customer the freedom to plan or optimize their network with the assurance that it will only make it more effective and with less interference.

C. REALISTIC LTE SCENARIO AND 5G COMPARISON

The realistic LTE scenario, depicted in Figure 9, is used to discuss the steps of the algorithm detailed in Section-III-D2 in the planning of a site, as detailed below:

1) **PCIs distribution calculation:** In this case, a consecutive spacing between PCIs within the same group is used. This way, groups of PCIs are not built, as any consecutive PCIs may form a group to be used in a site.
2) **Cells grouping per frequency:** There is only one frequency in this network, represented by EARFCN 6200, corresponding to a downlink frequency of 796 MHz. Therefore, to plan this cluster it is not necessary to make the cells grouping per frequency.
3) **NEIGHBORS analysis:** For each site, the neighbors of all the cells belonging to that site are analyzed, evaluating the percentage of co-localization of neighboring cells.
4) **PCIs interference calculation:** For each cell, a calculation of the interference of each PCI to that specific cell is performed. In this case, the most interferent PCI is 5, which is the one used by the most interferent site (S4) and the less interferent one is PCI 14, although PCI 2 also has minor interference. It is important to notice that the PCI interference depends on the neighbor interference and the PCI it uses, although a neighbor may be close to the base cell, it does not mean that both cover the same areas.
5) **PCIs allocation:** For S1, as all of the PCIs between 1 and 19 attributed to the cluster are already in use, it is necessary to reuse at least 3 PCIs. As S1 has 3 cells, the system finds the 3 consecutive PCIs that have the least interference with its neighbors and allocates them to the cells of S1. In this case, the system finds that the group (2,3,4) is the least interferent one and allocates it to the cells of S1.

Comparing the planning of PCIs on LTE networks may be compared and applied to 5G networks with minor changes. Metric, the tool intended to improve, does not work yet with 5G networks, so this technology was not focused on this paper although research was made in order to easily adjust the algorithm in the future for 5G resources planning. The calcule for the number of PCIs is done the same way, although for 5G the PCI count is higher than in LTE and there is one added rule to PCI allocation. This means that only the rules need to be changed, which is an easy adjustment to the algorithm.

D. IMPLEMENTATION DISCUSSION

The proposed and implemented algorithms, which are now integrated in the commercial Metric SaaS tool, are able to plan radio resources of any 3/4/5G network that uses Metric. Supporting network equipment from various manufacturers (Ericsoon, Huawei, ZTE, etc), this independence is a big advantage for network operators, turning this tool even more valuable.

Being an automatic and cloud-based system, time and computation on local machines is released. This allows system flexibility and mobility, being that it is available anywhere. Implementing this system on AWS contributes greatly in making it more reliable and always available on any device. When working with sensitive data, such as planning and maintaining cellular networks data, security is also one of the priorities, which is also improved with cloud services, where 94% of companies have seen improved security when using cloud services [42]. All of these factors have been taken into account in order to develop a product that can ensure good customer use as well as facilitate its maintenance.

This system also represents an innovation in the context of SON, enabling effective planning of network radio resources, namely SCs and PCIs, without any manual intervention on it. As human intervention is not required, the probability of errors decreases. The developed algorithms, were heavily tested to meet customer requirements for an optimal planning. Machine learning algorithms, in this specific case, do not apply, as there is no standard required for the algorithm to learn and apply. In this context, only an unnecessary overhead would be added, compromising the speed values at which the algorithm is able to carry out large planning's of mobile networks.

Although it is a cloud-based system, which has well-known limitations in terms of communication latency between components, the proposed system doesn't suffer from it, as this planning is not performed in real-time nor depends on real-time data. In fact, the planning mechanism is applied typically in two situations: in the initial planning of the network and when the network suffers changes that may impact with the planning, such as new antennas.

VII. CONCLUSION

In this paper, taking in consideration the similarities between UMTS, LTE and 5G in the planning of resources context, as well as the new cloud services and inspired in the SON paradigm, novel cellular planning algorithms for UMTS and LTE/5G are proposed.

As a proof of concept, an implementation of a cloud-based AWS network planning work pattern is presented. Based on real OSS network configuration and performance data, it is shown how it accurately estimates cells coverage, identifies neighboring cells and optimally plans SCs in a UMTS network and PCIs in LTE and 5G networks. For UMTS, the system operation is demonstrated with success for a small canonical scenario and a large realistic one. For LTE, the operation is demonstrated with success for a realistic LTE scenario. In the UMTS realistic scenario, the algorithm is able to avoid collisions between close neighbors and performs the whole planning of 12 484 cells in less than 8 seconds. For the LTE realistic scenario, for one site, the less interfering PCIs are found and allocated to its cells in less than 0.6 seconds. It is also demonstrated that the adjustments for the planning of the resources for 5G networks are easy, showing that this system is ready to be implemented using the Metric platform. As future work, the developed system shall be tested for 5G, when such a network is available in Metric. Integrated in Metric and capable of planning 3/4/5G networks of multiple vendors, this novel system brings new features to this tool, making it more attractive to the market.

ACRONYMS

AWS	Amazon Web Services
AWS EC2	Amazon Elastic Compute Cloud
AWS S3	Amazon Simple Storage Service
BSs	Base Stations
CRS	Cell Specific Reference Signal
DL	Downlink
DMRS	Demodulation Reference Signal
DTs	Drive Tests
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
ECGI	E-UTRAN Cell Global Identifier
ECI	E-UTRAN Cell Identity
GSM	Global System for Mobile Communications
KPIs	Key Performance Indicators
LTE	Long Term Evolution
MSs	Mobile Stations
OFDM	Orthogonal Frequency Division Multiplex
OSS	Operation and Support Systems
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PCI	physical cell identity
PSC	primary scrambling code
PSS	Primary Synchronization Signal
PUSCH	Physical Uplink Shared Channel
RAN	Radio Access Network
REGs	Resource Elements Groups
RS	Reference Signal
SaaS	Software-as-a-Service
SC	scrambling codes
SON	Self-Organizing Network
SSC	secondary scrambling codes
SSS	Secondary Synchronization Signal
UARFCN	UTRA Absolute Radio Frequency Channel Number
UMTS	Universal Mobile Telecommunications System
W-CDMA	Wideband code division multiple access

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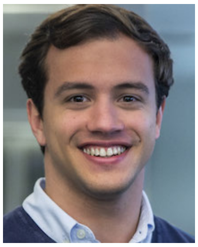

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