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Spectrum Reorganization and Bundling for Power Efficient Mobile Networks

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Abstract – **Technological improvements and evolving user requirements have led to operators running and supporting three distinct wireless access technologies, GSM, UMTS, and LTE. While the most recent layer (LTE) introduces improvements in spectral efficiency and peak data rates, the remaining layers are still required for supporting legacy devices and providing wider network coverage. In order to facilitate and reduce the cost of rolling out a new network, mobile operators often reuse existing sites. Radio frequency modules in base station sites house power amplifiers, which are designed to operate within a specific frequency band. Since some access technologies have spectrum split onto multiple bands, this results in operators installing multiple modules for each access technology. This paper quantifies the power savings that can be achieved by assuming that the available spectrum for an operator can be reorganized within a single band, and have multiple carriers bundled together to fully exploit the capabilities of modern equipment. These modifications are applied on all network layers, maintaining the same number of carriers and baseband capacity. For the presented case, this results in the elimination of at least four separate modules in each site, reducing the power consumption of by 31%. Indirectly, this also translates into a reduced site space of 40%. These savings are crucial for mobile network operators to reach the energy and carbon emission targets they have committed for.**

Keywords-component; energy saving, mobile network, mobile broadband, spectrum, base station, LTE, WCDMA, HSPA, GSM.

I. INTRODUCTION

Improvements in wireless technology and the ability of mobile devices to support and exploit mobile broadband have added pressure on the telecommunications industry. The versatility and capability of smartphones, and other connection-oriented devices, becomes seamlessly endless through a broadband connection. The availability of such devices and the rich multimedia experience they provide has been increasing the volume of data carried on mobile networks, with more users generating and sharing data. In a recent report, Cisco announced that in 2011, the global mobile data traffic has grown by a factor of 2.3, exceeding forecasts [1].

Mobile Network Operators (MNOs) are required to ensure that their networks can sustain this growth in data traffic. In order to provide additional network capacity, operators can carry out a number of upgrades. In dense urban areas, network capacity can be increased through the deployment of additional sites (large or small/outdoor or indoor), which increases capacity by reducing the effective covered area. A similar effect can also be achieved through higher-order sectorization, which increases the number of sectors in a site, generally going from 3 to 6 sectors. If available, capacity can also be increased for specific network layers through the use of additional spectrum. In order to sustain the overall evolution and higher data rates, deployment of the latest access technology, LTE, eventually becomes a natural step. Every country has a regulatory agency that controls the use and licensing of spectrum for different systems within its region. Spectrum is auctioned for a specific use, and the price it sells for is generally based on hype, and competitiveness among operators to acquire *'better'* spectrum. Even though cost of acquiring spectrum varies between different countries, spectrum often comes at a steep cost for any network operator [2].

In addition to controlling costs, and performance, network operators have in recent years also committed themselves to reducing the energy consumption of their networks [3] [4] [5], in an attempt to curb their carbon emissions and operational costs. Most, 75 to 80%, of the energy consumption in mobile networks is attributed to base station sites [3], which are deployed in large numbers and are individually very energy inefficient. The radio frequency (RF) equipment, designed to linearly operate around a specific frequency band, is the single element in a site that consumes most energy. Since, most access technologies use spectrum allocated onto different bands, operators are required to stack multiple RF hardware to cover the different bands, reducing the efficiency of the site further.

Over the last years, research in Cognitive Radio (CR) has taken a more prominent role. In a nutshell, CR involves the notion that a device can periodically scan (sense) it's surrounding environment and change communication parameters to improve the overall communication performance [6]. Since one of these parameters is frequency, this is hoped to, in the future, change the way that spectrum is allocated and managed. With the assumption that spectrum can be licensed and assigned differently, this paper looks at the potential energy gains for MNOs, and the mobile industry in general, if the number of RF modules in base station sites can be reduced, while maintaining the same capacity and service quality.

Section II presents a case of how spectrum is allocated in Germany. The following sections explain the characteristics of different frequency bands, and how a typical site can be reorganized to improve its overall energy efficiency.

II. SPECTRUM ALLOCATIONS – GERMAN CASE

The German market for mobile communication services is shared amongst four MNOs: Vodafone D2 (VF), E-Plus (EP), Telekom Deutschland (DT), and Telefonica O2 Germany (O2). In August 2000, auctions in Germany for UMTS spectrum raised €50.8 billion, topping the previous record held by

the UK of €38.3 billion [7]. More recently in May 2010, auctions for LTE spectrum in the 800MHz and 2600MHz band were carried out. As noted in Figure 1, the three larger MNOs achieved spectrum in both bands while EP only acquired 20MHz of paired, and 10MHz of unpaired spectrum in the 2600MHz band. The term 20MHz of paired spectrum refers to two 10MHz chunks, separated by a sufficiently large guarband, for supporting Frequency Division Duplex (FDD). While unpaired spectrum costs less, its use by MNOs remains uncertain. Amongst other possible options, this spectrum can be used for small home base stations (femtocells), wireless backhaul, channel/carrier aggregation, or Time Division Duplex (TDD) communication.
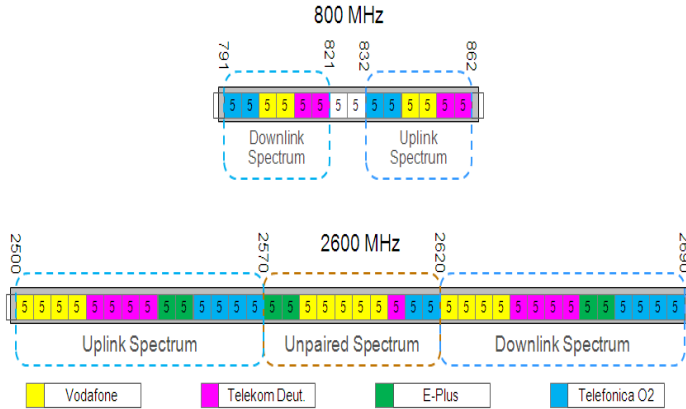

Figure 1 – LTE frequency allocation in Germany [8], for the 800MHz and 2600MHz bands as divided by operator. This shows how much spectrum each operator is licensed for, and the way that this spectrum is spread, on the two frequency bands.

For WDMA/HSPA, MNOs in Germany have a cumulative bandwidth of 153MHz of which 118.8 MHz is paired. By only considering paired spectrum, EP has sufficient spectrum to support up to eight 5 MHz carriers. On the other hand O2 and VF both have spectrum for six carriers while DT has four, all in the 2100 MHz band. On the GSM layer, all four MNOs own spectrum on two separate bands to a total of 209.2 MHz, divided 69.6 MHz and 139.6 MHz on the 900 MHz and 1800 MHz bands respectively. Having different amounts of spectrum for the different layers reflects the different network evolution strategies of each MNO.

A. Characteristics of Different Frequency Bands

In wireless communication *link budget* and *propagation loss* are common terms used to describe communication link quality. A link budget is carried out to calculate the RF power received by taking into account all the gains and losses of the signal along its path. A major component of a link budget is propagation loss, which measures the degradation of a signal as it travels (propagates) from transmitter to receiver. A simple free-space link budget can be carried out through the Friis transmission equation [9]. Assuming that a transmitter and receiver have an antenna gain G_t and G_r respectively, and a signal with power P_{Tx} is transmitted, this equation takes into account the distance d and the frequency f of the signal to estimate the received signal.

$$Pr = Pt + Gr + Gt + 20*\log_{10}(\lambda/4\pi d) \tag{1}$$

$$\lambda = c / f \tag{2}$$

The equations (1, 2) show that the received power is inversely proportional to the frequency. This means that as the frequency decreases, for a given transmit and received power, communication can be carried out over a longer distance. Alternatively it can also be looked at as; the transmitter can transmit at lower power for achieving the same received power at the same distance. This is the reason why at higher frequency bands, paired spectrum is split such that uplink is carried out on the lower bands, taking into consideration power limitation of mobile devices.

In mobile communication, more detailed and realistic propagation models, such as the Hata model, described below by Eq. 3, are used to estimate the degradation in signal quality [10]. By comparing the two LTE spectrum bands, Figure 2, it can be noted that going from the 800 MHz to 2600 MHz the signal quality for the same distance degrades by around 14 dB. In reality, this is more likely to be around 10 dB, since antenna gains at 2600 MHz are generally 4 dB higher [11].

$$L_u = A - C_H + [44.9 - 6.55 * \log(h_B)] * \log_{10}(d) \tag{3}$$

where: h_B and h_M are base station site and mobile device height respectively, d is distance, f represents transmission frequency, and:

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_B) \tag{4}$$

$$C_H = 0.8 + (1.1*\log_{10}(f) - 0.7) * h_M - 1.56 * \log_{10}(f) \tag{5}$$

While in a dense urban area (interference limited scenario) this would not have any major impact, due to the relatively short distance between adjacent sites, in suburban and rural areas this will have an effect on the number of sites required to ensure the same level of coverage. For instance, the signal strength received at a distance of 4 km at 800 MHz can be achieved on the 2600 MHz band, while not considering the additional antenna gain, at a distance of no more than 1.6 km. This, and the fact that less spectrum is available, highlights why spectrum at the 800 MHz band is more expensive.
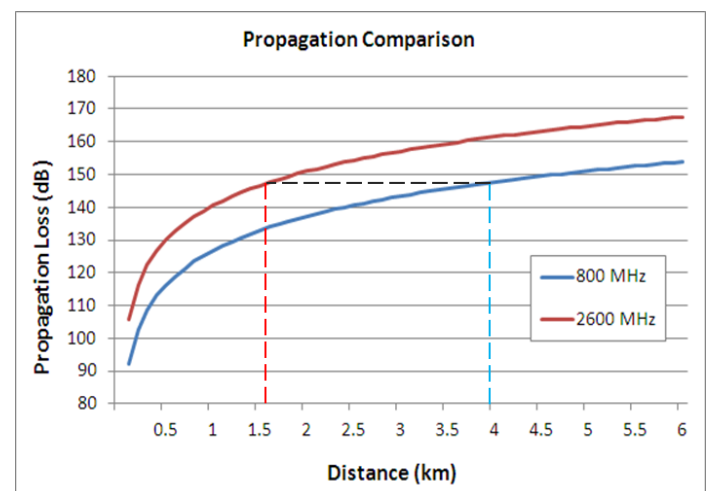

Figure 2 – Comparison of propagation loss for the two LTE bands using the HATA model (3). A base station (h_B) and mobile (h_M) height of 35m and 2m respectively are assumed. This highlights the importance of having spectrum at lower end of the spectrum.

III. BASE STATION SITE CONFIGURATION

When planning a network, MNOs carry out an intense exercise to estimate the necessary capacity requirements for different areas. Based on this study, ideal base station sites locations are selected. Contacting and setting up agreements with site owners could be difficult, restricting specific site locations. This is why, whenever an operator is required to install an additional network layer, the first option is to reuse existing sites. This also allows for the reuse of backhaul, power supply, equipment racks, and cooling already in place. On the practical side, a commissioned site facilitates and speeds up deployment.

For a particular layer, each base station site houses an array of equipment that is necessary to support communication to the mobile devices as well as to the rest, core, of the network. This paper focuses on the RF Module (RFM), which houses the power amplifiers, and the System Module (SM) which provides functionalities related to baseband processing, control and backhaul transmission. The RFM is the module in a site that consumes most energy, with estimates ranging from 50% to 65% [12]. Additional equipment is required to ensure the continuous operation and safety of the site. Such equipment includes, battery backup for potential power failures, lighting, and if necessary active cooling. Modern equipment can operate at higher temperatures, replacing the need for bulky and energy hungry air-conditioning, with passive cooling.

LTE employs 2x2 MIMO, requiring transmission over two separate chains and hence RF modules. In the case for WCDMA/HSPA, the number of RFMs installed depends on the amount of active carriers, and the number of carriers supported by the equipment. Older equipment versions support fewer carriers, meaning that upgrading a site to three or more carriers requires multiple RF modules. Currently, a single multi standard RFM can support up to four 5 MHz carriers [13]. This means that in the case of LTE, upgrading to a second 20 MHz carrier still requires a second RFM. However new equipment is expected to be capable of supporting bandwidths in the range of 40 to 60 MHz, making it possible to have multiple 20 MHz LTE carriers on the same modules. The challenge for achieving this is the circuitry that controls linearization, which has to operate over a wider bandwidth.

IV. BASE STATION SITE AND NETWORK MODELING

A. Proposed Adjustments to Allocations

This paper looks to reduce the power consumption of existing base station sites by reorganizing spectrum from multiple bands and exploiting the full capabilities of existing base station equipment (Figure 3). By doing this, MNOs can run all network layers, with the same amount of bandwidth, but with fewer RFMs. Even if the reorganization of spectrum will not be possible, some of the presented concepts can still be applied to existing sites using multiple RFMs within the same band. MNOs can assign the specific frequency band depending on the type of environment. By focusing all carriers (bandwidth) within the same frequency band and bundling them up to the same RF module reduces the need for multiple RFMs, making the site more energy efficient, and requiring less space at the site. The latter allows for a potential reduction in rental cost, the requirement of less cooling, and limited visual pollution.
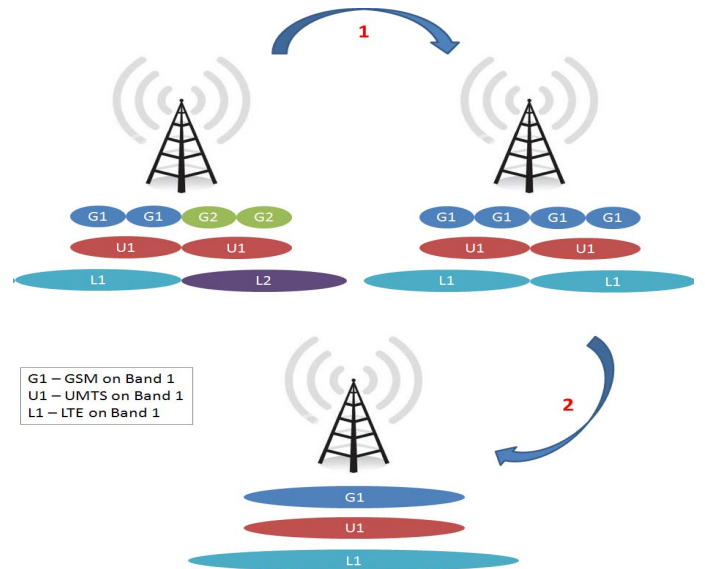

Figure 3 – Spectrum and equipment changes for reducing the power consumption of mobile networks. First step is to move carriers to a common band, while the second bundles all carriers and exploits modern equipment.

A further assumption is that mobile terminal manufacturers are able to incorporate and support the individual bands. This ensures that no matter which band is available the device is able of connecting. With the continuous influx of devices, this issue is unlikely to be a show-stopper. With LTE still in its infancy, 2011 has already seen a considerable wave of devices to hit the market. Some of the released devices are also dual-mode enabled, supporting both TDD and FDD [14], demonstrating the ability to embed added flexibility in these devices.

B. Power Consumption

When estimating the energy consumption of base station sites over a specific network area, the number of sites and specific configuration of each site is required. The configuration of each site gives an idea on the different technologies supported, transmission power, sectors and other parameters affecting the power consumption. This is also impacted by the age of the equipment. In a bit over a decade, a specific equipment vendor will have released four versions. Besides adding new features, supporting legacy/new standards, and facilitating control, new equipment is also more energy efficient, shown in Figure 4.
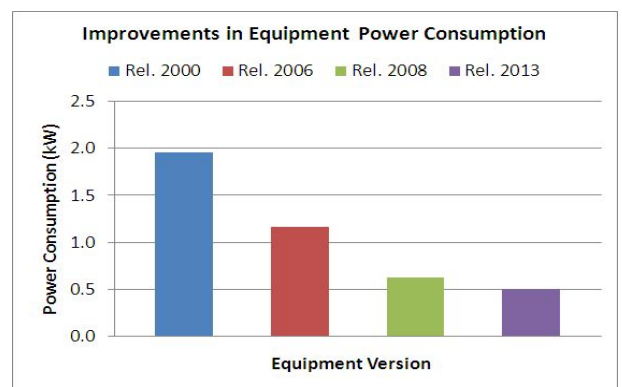

Figure 4 – Energy consumption comparison for four different equipment versions, all configured in the same way (3 sector site with 20W transmission power per sector). The release year for each version can be noted in the legend at the top of the figure.

Table 1 – Power consumption values at full load for a 3 sector macro base station site at different configurations. The configuration *x+x+x* refers to three sectors with *x* active carriers for each sector each transmitting at 20 Watts.

	Consumption for Different Configurations				
Layer	1+1+1	2+2+2	3+3+3	4+4+4	6+6+6
GSM	-	1800W	-	2300W	2700W
WCDMA/ HSPA (5MHz)	750W	1200W	1400W	1700W	-
LTE (20MHz)	1400W	*2000W*	-	-	-

For the purpose of this paper, all calculations are carried out assuming a single equipment version, more specifically the 2008 release version. This isolates reductions in power consumption as a result of the proposed concept of reducing the number of RF modules from base station sites.

Table 1 gives an overview of the power consumption for a typical 3 sector macro site with a transmission power of 20W per sector. These values are based on power models which are partly based on equipment measurements. Where applicable (based on the configuration) these models are in line with values presented in a study on base station site power consumption [15]. The table instantly points out the impact that MIMO has on the power consumption of a site.

C. Site and Equipment Assumptions

Since all MNOs own spectrum for the different access technologies, it is assumed that all are required to provide these services. By having different evolution strategies, different operators are likely to evolve their macro sites differently. For instance, by looking at the case of LTE, different operators have acquired different amount of bandwidth, ranging all the way from 30 MHz by EP up to 85 MHz by VF. In order to simplify the study, the analysis is carried out on a single 3 sector macro site. In addition, for a fairer comparison of results, all network layers are assumed to be running at full load.

While this paper has been setup around LTE, as mobile networks evolve, adjustments to GSM and WCDMA networks can still provide improvement in the energy efficiency of the network. The purpose of GSM networks is to provide more extensive network coverage, support GSM-only capable devices, and provide connectivity for Machine-to-Machine (M2M) communication. While operators might in the future consider a reduction on the GSM layer of the network, in this case it is assumed to be fully maintained.

For the WCDMA/HSPA layer it is assumed that operators can upgrade sites with up to four 5 MHz carriers. This provides enough capacity to accommodate traffic growth and delay the need for additional sites and the rollout of LTE. Statistics from a MNO shows that different sites have different equipment versions. Older versions require an RFM for every carrier on every sector. Later versions of the same equipment support multiple sectors and carriers on single RFMs. Since a number of sites have been upgraded it is assumed the equipment can support three sectors and up to two carriers.

Since the assumed (2008 version) equipment can support three sectors, with up to four carriers, it is assumed that MNOs can go from having multiple carriers on multiple RFMs to having all carriers on a single RFM. This is a way of exploiting the capabilities of existing equipment, which is more energy efficient than having the same number of carriers on multiple modules. The advantage of having multiple RFMs is that in the case of a fault or failure, traffic can still be served by the other modules, limiting the impact on subscribers within the area. In addition, having multiple RFMs provides an added opportunity for network optimization techniques to exploit traffic variations and switch off some of the modules/carriers during hours with low traffic.
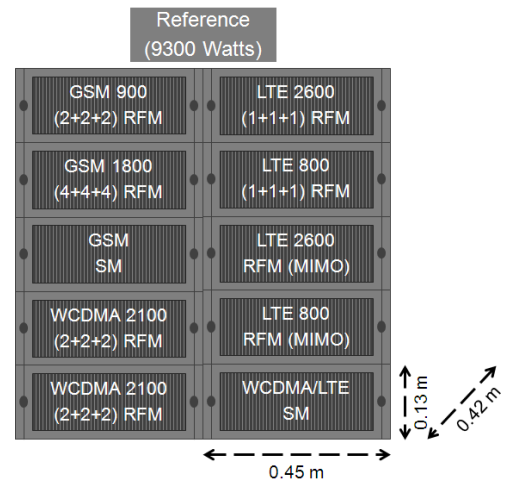

Figure 5 – Overview of the RFMs and SM required for a regular three sector site to provide communication on all network layers. Four LTE RFMs are added to provide MIMO capabilities for the two frequency bands. The number of carriers (x) in each sector are presented in the RFM block (x+x+x).

Figure 5 provides an overview of the communications equipment required in a base station site to provide access to all access technology layers spread over five different frequency bands. With regards to the required space, each module is assumed to have the dimensions, 0.45x0.13x0.42 meters, giving a volume per unit of 25 liters [13].

V. RESULTS

Three separate upgrade stages are considered, each building onto the previous. These upgrades do not reduce or limit the amount of available spectrum and baseband capacity of the site, but exploit the capabilities of modern equipment, and reorganization of licensed spectrum. Besides presenting the power savings of the different upgrade stages, space savings at the site are also provided.

For the first upgrade stage, left side of Figure 6, both LTE carriers are pushed onto a single band, requiring a single RFM. Since 2x2 MIMO is assumed, using a single band effectively reduces the number RFMs in the site from four to two. This reduces the power consumption of the site from 9300 Watts to 8500 Watts. Given the equipment dimensions, this also results in a space reduction by 50 liters from the original setup of 250 liters.

In the second stage, right side of Figure 6, the site is improved further by replacing the two separate WCDMA/HSPA RFMs with a single module supporting all four carriers. This reduces the power consumption of the site even further to 7800 Watts, giving an overall power consumption reduction of about 16%. This reduces another unit saving a further 25 liters of space.
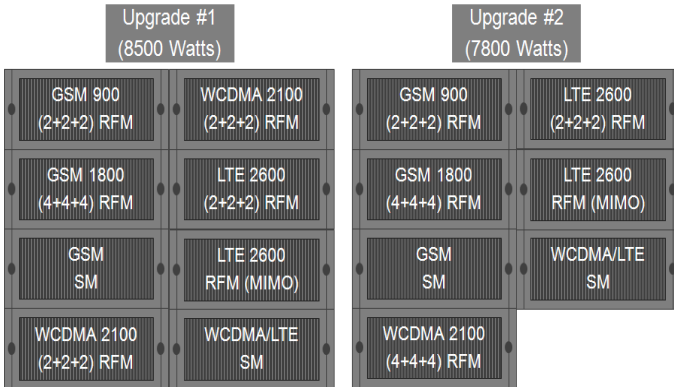

Figure 6 – Two upgrade stages for making a base station site more energy efficient. Upgrade #1 focuses on putting all two LTE carriers to the same RFM. On the second stage, all four WDCMA/HSPA carriers are shifted to a single RFM. In both cases the same number of carriers is maintained. The same is assumed for the baseband capacity of the system modules.

In the final stage, Figure 7, the equipment for GSM is also upgraded. A single GSM module can currently support up to six carriers on three sectors [13]. This means that the assumed configuration of the existing site, having four carriers on the 1800 MHz band and two carriers on the 900 MHz band, can be upgraded to have all six carriers on one of the two frequency bands. This reduces the power consumption of the site to 6400 Watts, a total reduction of 31%. While the results presented focus on a single base station site, these savings can be scaled across multiple operators and multiple sites considerably affecting the overall power consumption of mobile networks.
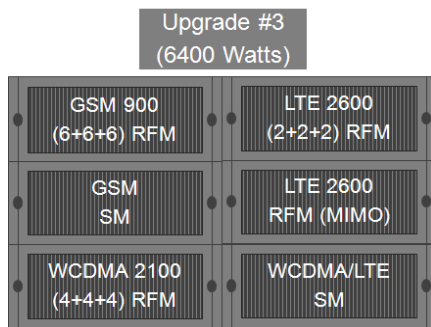

Figure 7 - Third upgrade that involves combining all GSM carriers onto a single frequency band. This reduces another RF module from the base station site, giving a minimalistic configuration for a site to support all three technologies over the same amount of spectrum.

Simply by looking at the number of modules, the proposed modifications reduce four out of the ten modules, a reduction of 40%. This is equivalent to a reduction in volume of 100 liters. Such a considerable saving in space could result in fewer equipment racks/cabinets, potentially reducing the amount of rented space, and costs for some of the sites.

VI. SUMMARY AND CONCLUSIONS

This paper looks at the potential power savings by exploiting the capabilities of modern equipment and reorganizing spectrum. Operating multiple carriers on different frequency bands requires additional RF equipment to supports the different bands. By putting all carriers on the same band, and using equipment that can support more carriers, base station sites can maintain their current capacity, while at the same time making the site more energy efficient and compact. The single band to choose can be selected based on the requirements within a specific area, with suburban and rural areas adopting the lower frequency band, maximizing coverage with fewer sites.

By applying the three steps considered, , the cumulative power consumption of the site is noted to reduce by 8.5%, 16%, and 31% respectively, when compared to the power consumption of the reference site (9300 Watts). All major MNOs have committed themselves to reduce their carbon emissions, mainly by reducing energy consumption. This has to be achieved while also upgrading network capacity through the deployment of additional carriers, sites and the rollout of LTE. The modifications proposed in this paper, together with other energy saving features that exploit redundancies and traffic variations, could have a considerable impact on achieving these goals.

While difficult to consider changes in the way spectrum is allocated on a short-term basis, the possible gains presented in this paper are targeted to provide an incentive for MNOs to replace older site equipment and consider alternative frequency plans for upgrading mobile networks and meet growing traffic demands.

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