A Novel Cell-Sweeping based Base Stations Deployment for Coverage, Throughput, and Energy Efficiency Enhancement

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***Abstract*—Network coverage is an increasing concern for the Quality of Service (QoS) targets of new mobile technologies. New solutions designed to fulfill the requirements of the existing fifth-generation (5G) and upcoming sixth-generation (6G) emerging scenarios are based on deploying a high number of network access points (APs), which tend to considerably degrade coverage and cell-edge performance due to added interference and increase the energy consumption of cellular systems. In this paper, we present new results on our recently proposed novel concept of cell-sweeping that aims to minimize the coverage dead-spots and improve cell-edge user performance. More specifically, the concept is explored further in this paper analyzing the impact of different cell-sweeping configurations and evaluating the potential benefits towards achieving energy efficiency. By means of system level computer simulations, it is shown that cell-sweeping provides energy savings of 11% and 26.5% for a similar average and cell-edge user throughput performance, respectively, when compared to the conventional static cell deployment in a typical urban macro cell scenario.**

***Index Terms*—Cell-edge, Cell-Sweeping, Cellular Technologies, Energy Efficiency, Uniform Coverage.**

I. Introduction

The high traffic demand and ever increasing requirements of mobile users in terms of new and high-quality services lead to a constant necessity for mobile technologies advancements and improvements. The network capacity, throughput, and latency are typically the Key Performance Indicators (KPIs) used to evaluate and optimize the network performance, establishing the foundations for use cases such as enhanced broadband, ultra-low latency services, and massive communications. However, there are other important challenges in mobile networks that require attention and may impact future deployments. The network smooth connectivity, coverage quality, and the cell-edge interference problem are examples of concerning network issues, whose good performance is critical for the enhanced operation of the existing and upcoming technologies.

Several new solutions and designs targeting future cellular network requirements have provided encouraging results in terms of capacity and coverage. This is the case for densification, relays, Coordinated Multi-Point (CoMP), or the use of millimeter waves (mmWaves) [1]–[4]. However, several drawbacks and challenges are continuously associated to most of these new mechanisms. These drawbacks range from technical feasibility to economic viability. In addition to the considerable deployment costs and increasing energy consumption [5], network densification is associated to a significant increase in network interference with massive impact on coverage quality and cell-edge user performance [5], [6]. The CoMP and beamforming based solutions are typically complex and require heavy computational processing in the backaul as these mechanisms result from coordination between different access points (APs), and operate based on channel knowledge [7], [8]. Concerns regarding the high attenuation and short cell-radius of mmWaves, as well as the traffic overhead of new protocols and User Equipment (UE) battery consumption of Device-to-Device (D2D) communication systems have also been raised multiple times [4], [9]. Additionally, the traditional cellular deployments are based on sectorized Base Stations (BSs) using different cells with directive antennas. While this configuration maximizes the performance at the locations closer to the antenna main beam, it does not overcome the cell-edge problem.

In our earlier paper, the novel concept of cell-sweeping was introduced [11]. An initial presentation of the concept was conducted, consisting of an extended description of the technology together with some initial analysis regarding the effect of sweeping in the antenna pattern and received power. Additionally, the user throughput gains were explored in a comparison between the Round-Robin (RR) and Proportional-Fair (PF) schedulers using a Long Term Evolution (LTE) system level simulator. In this direction, part of Section II briefly introduces the concept based on [11] in order to provide some background and context to the reader. Nonetheless, this paper focuses on other important aspects and metrics of cell-sweeping that were not explored before. Namely, the cell-sweeping effect on the network wideband Signal-to-

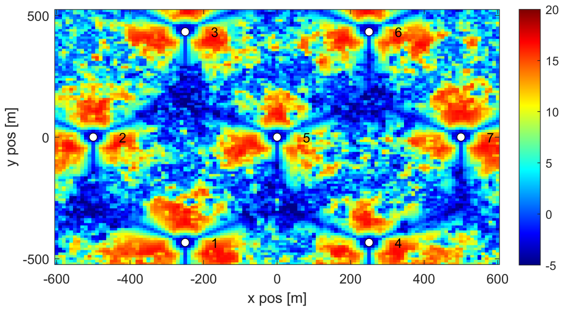

Fig. 1: Wideband SINR Map in a Conventional Cell Deployment [11].

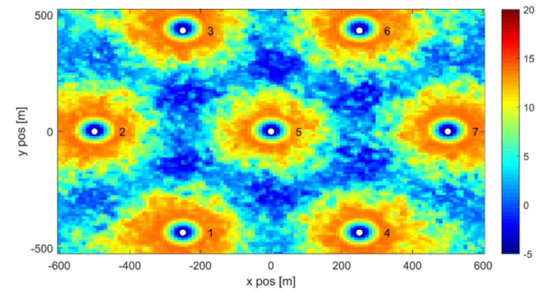

Fig. 2: Wideband SINR Map after a Cell-Sweeping Simulation [11].

Interference-plus-Noise Ratio (SINR) and modulation coding scheme (MCS), computing optimal sweeping configuration parameters, and the potential benefits of cell-sweeping on the energy efficiency are studied and presented from different perspectives.

This paper is organised as follows. Section II briefly introduces the cell-sweeping concept and its incorporation into the standard antenna gain expression, as well as the impact of cell-sweeping on the wideband SINR and MCS selection. In Section III, different cell-sweeping configuration parameters are explored and discussed. Section IV presents a view on how the cell-sweeping can be used for energy efficiency purposes, and Section V concludes the paper, presenting a summary of the main outcomes and challenges.

II. The Cell-Sweeping Concept and Network Impact Overview

This section introduces the cell-sweeping concept and outlines its impact in the network through the wideband SINR analysis, incorporating an antenna gain expression that considers the effect of sweeping the BS cells.

A. The Cell-Sweeping

The most common way of deploying BSs in cellular networks is through a tri-sector static architecture. Let us consider Figure 1 where the wideband SINR distribution in a conventional 7 tri-sector BS network considering a typical urban scenario is shown. It becomes clear that several locations suffer from low SINR (dark blue areas), while others are constantly being illuminated by the centre of the cells, leading to good SINR (intense red) and hence, better performance. Therefore, this configuration results in an unbalanced network resource distribution. The dark blue areas are typically referred as cell-edges. These cell-edges can be classified as inter-site cell-edges defining the coverage dead-spots between cells of different sites, or intra-site cell-edges for coverage dead-spots between cells of the same site. The degraded network conditions in these locations are often related to interference. Nonetheless, they also result from the typical higher geographical distance to the serving BS or higher angular distance relatively to the direction of the antenna transmission. This angular difference between the orientation of the sector and a certain location or user is termed as the off-boresight angle. Therefore, it can be stated that the cell-edge and coverage dead-spot problems are also function of the off-boresight angle and distance to the serving and neighboring BSs.

The autonomous cell-sweeping mechanism aims to provide a much fairer resource distribution for any location around the site serving area. This can be achieved by sweeping the cells to provide uniform coverage. This mechanism results from a continuous shift in the azimuth plane of the BS antenna sectors. The continuous radial cell movement can constantly occur in a certain direction (clockwise/anti-clockwise) or by continuously scanning a limited range of the azimuth plane. The former operation is termed as full sweeping and the latter as partial sweeping. The cell-sweeping mechanism operates continuously and does not need any information whatsoever from the network or the users. In this direction, it differs from other solutions based on beamforming/beam-sweeping, and mmWaves since it does not require further feedback, channel knowledge, or user tracking. Therefore, it avoids some of the additional protocol overhead and backhaul processing. Furthermore, the cell-sweeping can be deployed in high frequency bands as well as low-frequency bands. Thus, it is also applicable to rural and low populated environments.

The application of the cell-sweeping mechanism in the same environment of Figure 1 results in the wideband SINR heatmap from Figure 2. It is a representation of a clockwise full sweeping scenario where all BS sectors synchronously rotated in steps of 10º per Transmission Time Interval (TTI) (1 millisecond), until completing a full 360º radial movement. In comparison to the result from Figure 1, cell-sweeping leads to a much more uniform distribution of the wideband SINR, significantly mitigating the coverage dead-spots and cell-edge performance drop in both inter-site and intra-site locations. This impacts the cell-edge user experience, as its throughput will be significantly improved. The lower intensity of the SINR towards previous cell-centre locations is a consequence of the sectors not radiating constantly at their maximum into a fixed direction.

B. Antenna Gain and SINR System Model with Cell-Sweeping

The concept of cell-sweeping relies upon a continuous or discrete sweep or rotation of the antenna radiation pattern in the azimuth (horizontal) plane. In a typical antenna diagram modeling expression, the antenna gain depends on the angle between the direction of the antenna main lobe and the position of a user in what was already termed as the off-boresight angle. This off-boresight angle, ϕ, can be computed as:

$$\phi = \phi_{B_x,U} - (90 - \phi_a) \tag{1}$$

where $\phi_{B_x,U}$ represents the horizontal angle between the x-axis of the reference BS, B_x, and a certain user, U, and ϕ_a represents the azimuth angle, *i.e.*, the angle between the sector orientation and the geographic north. The azimuth angle is a sector deployment configuration parameter. The cell-sweeping is enabled by making the azimuth angle a dynamic parameter since it defines the direction of the cell-centre of each sector. Therefore, the cell-sweeping effect is obtained by changing this azimuth value according to a certain step size A, in degrees, and a sweeping period P, in milliseconds or TTIs. The azimuth angle, ϕ_a, is modelled as follows [11]:

$$\phi_a(t) = mod(\phi_{a_{t-1}} \pm xA, 360) \tag{2}$$

where the $mod()$ function ensures that the azimuth ranges between 0 and 360º, $\phi_{a_{t-1}}$ is the initial or previous azimuth set, and x is given by:

$$x = \begin{Bmatrix} 1, & mod(t, P) = 0, \\ 0, & mod(t, P) \neq 0. \end{Bmatrix}. \tag{3}$$

This means that $\phi_a(t)$ will result from the previous azimuth $\phi_{a_{t-1}}$, shifted by A degrees every P period.

The wideband SINR is computed considering the network hexagonal layout from Figures 1 and 2. Let us number the serving cell of the system as 0 and the interfering neighboring cells from 1 to 6. The wideband SINR presented in the previous figures is a representation of slow scale channel attenuation where the multipath component of received signals is averaged out. In cellular networks it is computed as follows:

$$SINR = \frac{P_{R_0}}{N + \sum_{i=1}^{I} P_{R_i}} \tag{4}$$

where P_{R_0} is the received power from the serving cell and P_{R_i} the received power from neighboring or interfering cells. Therefore, $\sum_{i=1}^{I} P_{R_i}$ models the amount of interference in the system, where I represents the total number of interferers with $i \in \{1, ..., I\}$. The thermal noise power is given by N. Using the assumption that small scale fading is averaged out by the receivers, the received power, P_{R_k}, can be written as:

$$P_{R_k} = P_{T_k} G_k (C_s d_k)^{-\alpha} exp(\beta X_k) \tag{5}$$

where P_{R_k} and G_k are the transmit power and antenna gain of the $k^{(th)}$ cell, respectively, d_k is the distance between a user and the $k^{(th)}$ cell, and C_s and α are environment dependent and represent the path loss constant and exponent, respectively. The cell identification parameter $k \in \{C\}$ where $C = \{I\} \cup \{0\}$. Finally, $\beta = ln(10)/10$ and X_k denotes a zero-mean Gaussian random variable assumed to model shadowing with variance ${\sigma_k}^2$.

The sweeping mechanism will affect the parameter G_k of the SINR calculation considering the modification of the off-boresight angle derivation in (1) and (2). Therefore, G_k in a certain location will vary according to the off-boresigh angle, ϕ, whose variations depend on the sweeping parameters A and P. Applying this mechanism into the SINR presented model, the heatmap from Figure 2 is statistically represented with the Cumulative Distribution Function (CDF) from Figure 3. This CDF confirms what is expected from the concept. The 5^{th}-percentile gets a significant improvement of 2.2 dB in this scenario, and the overall network performance improves apart from the high percentiles. The high percentiles represent the initial cell-center locations. Since the BSs are sweeping, there are no locations being consistently illuminated by the centre of the cell. Thus, a drop in performance is expected in these locations. However, this can be overcome by using appropriate scheduling policies.

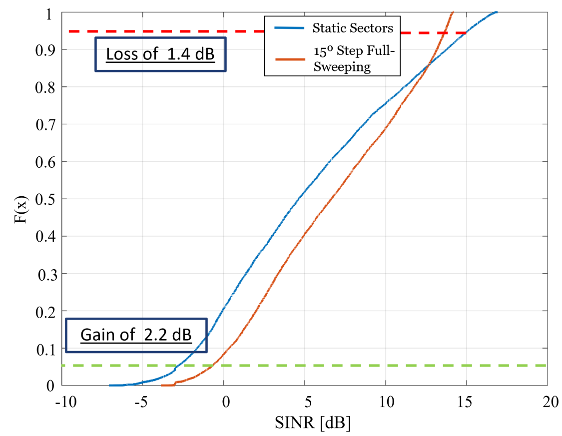

Fig. 3: Cell-Sweeping and Static Wideband SINR CDF comparison.

While the wideband SINR was being equally measured in all locations, in what can be approximated to a RR performance, Figure 4 shows the Channel Quality Indicator (CQI) distribution of conventional cell deployment and cell-sweeping considering a PF scheduler. In this scenario, there is an overall performance shift towards the higher CQI values with cell-sweeping. Therefore, when applied together with PF, cell-sweeping not only enhances the 5^{th}-percentile performance but also the entire network. This result translates into data rate gains. The general network performance enhancement resulting from the application of PF scheduling policies with cell-sweeping is related to the balanced operation of this scheduler. Firstly, PF prioritizes users with good network conditions, typically located closer to the cell-centre. Secondly, since the cells are sweeping, all users will be close to the cell-centre at some point. Therefore, they will have more opportunities to be served with very good SINR irrespective of their location, maximizing the overall network performance.

III. Effect of Tuning the Cell-Sweeping Parameters

In this section, the effect of changing the sweeping parameters A and P will be explored. The presented cell-sweeping performance was achieved through LTE system level simulations following a Monte Carlo implementation. The cell-sweeping was developed and included into the simulator through the antenna model modification presented in eq. (2)

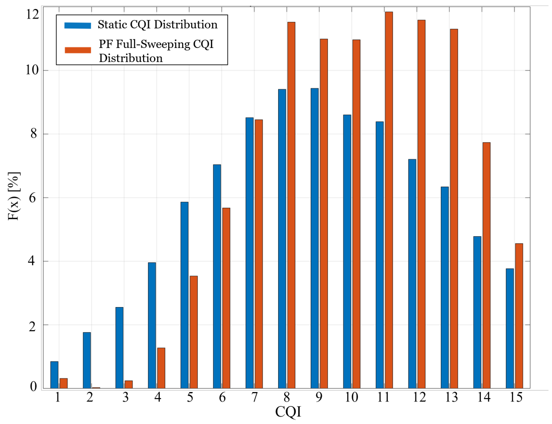

Fig. 4: Comparison of the CQI distribution of a full cell-sweeping deployment and a traditional cell architecture.

TABLE I: Simulation Parameters.

Parameter	Setting
Carrier Frequency	2.14 GHz
System Bandwidth	10 MHz
Cellular Layout	Tri-Sectorial Hexagonal Grid
Path loss model	Urban scenario from 3GPP [10]
Shadowing Standard Deviation	8 dB
Antenna Model	3GPP 2D Antenna [10]
eNodeB Tx Power	46 dBm
Inter-Site Distance	500 m
Cell-Sweeping Characteristics	
Sweeping Amplitude	Steps of 1°, 15°, 35°, and 65°
Sweeping Period	1 ms, 10 ms, 30 ms, and 60 ms
Sweeping Type	Full-Sweeping
Simulation Time	30 laps (no. of 360° rotations)

which will consequently affect the SINR due to its dependency with the antenna gain, G_k. A summary of the simulation parameters is provided in Table I. The network layout follows the same architecture of Figure 2. Due to the optimized results presented in Figure 4, the PF scheduler is deployed and 50 UEs/cell are randomly dropped. All simulations were applied following a typical urban scenario. In this direction, a shadow fading standard deviation of 8 dB was considered. The results compare the different cell-sweeping configurations with the conventional three static sectors architecture. The cell-sweeping configurations are detailed in the following subsections. The comparisons are performed focusing on the throughput CDF distribution with particular emphasis in the 5^{th}-percentile and average user throughput. The 5^{th}-percentile is typically used for evaluation of the cell-edge performance, while the 95^{th}-percentile tends to represent the cell-centre [12]. In the following, different sweeping configurations are explored. The sweeping amplitude, A, will be scanned from 1º to 65º, while the sweeping period ranges from 1 TTI to 60 TTIs. All results consider a full-sweeping deployment.

Despite being implemented in an LTE system level simulator, the cell-sweeping does not affect the digital baseband. It is a radiofrequency level technique, hence applicable to the legacy (fourth-generation (4G)/ fifth-generation (5G)) and future cellular networks (sixth-generation (6G)). Furthermore, the cell-sweeping can also cope with other technologies such

TABLE II: Cell-sweeping performance compared to the static scenario for different sweeping amplitudes keeping the sweeping period fixed at 1 TTI.

Throughput with Proportional Fair [Mbps]						
Metrics		**50 Users / Cell**				
		Full Sweep 30 laps				**Static**
		1º/TTI	**15º/TTI**	**35º/TTI**	**65º/TTI**	
%ile	**5**	0.116 +74.2%	0.15 +125.5%	0.153 +130%	0.15 +125%	0.068
	50	0.348 +14.5%	0.431 +41.6%	0.44 +44.5%	0.439 +44.3%	0.304
	95	0.757 +6%	0.861 +20.5%	0.874 +22.3%	0.863 +20.7%	0.715
Average		0.387 +13.3%	0.462 +35.2%	0.472 +38.2%	0.469 +37.5%	0.341

as the massive multiple-input multiple-output (mMIMO) or mmWaves. These integrated solutions are expected to be investigated in subsequent iterations of the concept. In the following results, the green-colored digits represent the percentual improvement of cell-sweeping compared to the static scenario.

A. *Sweeping Amplitude*

The sweeping amplitude, A, defines the amplitude in degrees of the sectors' sweeping step, during the radial movement in a certain direction. The sweeping period assumed for this analysis is the smallest time unit used to schedule users in cellular networks, *i.e.*, 1 ms, and defined as 1 TTI. This sweeping period setting is considered due to the fact that high sweeping speeds are expected to provide better performance. The performance results when keeping the sweeping period fixed to 1 TTI and changing the sweeping amplitude are summarized in Table II for $A = \{1, 15, 35, 65\}°$. This table benchmarks the performance of different settings to the traditional static scenario.

The cell-sweeping with PF leads to throughput gains in all metrics presented in Table II, irrespective of the cell-sweeping parameter configuration. This is in accordance to what was previously explained in the CQI analysis, in Figure 4. In addition, cell-sweeping operates better with sweeping steps that lead to scheduling users with as much different SINR conditions as possible in consecutive TTIs. If sectors sweep 1º every TTI, a higher uniformity exists in the resource distribution and hence, higher 5^{th}-percentile performance would be expected since it is guaranteed that all locations in the network will be cell-edge and cell-centre at some point. While this would be the case for a RR scheduler due to the lack of any prioritization mechanism, it is different with the PF that balances fairness and performance maximization based on the UE SINR conditions. In this direction, despite all locations being cell-centric and edgy at some point when the sectors sweep $1°/$ TTI, it also means that the variations in the radio channel are lower. Therefore, UEs that are initially at the cell-edge need to wait several TTIs until being closer to the cell-centre. On the other hand, when the sweeping step is higher, like 15º or 35º, users that initially were at the edge of the cell will be in good network conditions every 2 or 3 TTIs. This takes advantage of the PF operation and results in enhanced performance.

Concretely, the fact that most UEs will be served with good network conditions every 2 or 3 TTIs not only optimizes the 5^{th}-percentile but all throughput presented metrics. When the point where most users are served with good conditions in a relative short period is reached, the performance for different sweeping amplitudes does not change significantly. Thus, the performance difference between A equal to 15º, 35º, and 65º is small (considering uniformly distributed users).

B. Sweeping Period

The sweeping period, P, defines the number of TTIs that the sectors are stopped towards a certain direction until the next step A occurs. In this analysis, P will be scanned for $P = \{1, 10, 30, 60\}ms$. The sweeping amplitude, A, will be constant in this case. While 1 ms was assumed in the previous sweeping amplitude study, in this case, the sweeping amplitudes that provided better performance in the previous analysis are assumed. One saw that the sweeping performance was similar for $A = \{15, 35, 65\}°$. In practical terms, smaller azimuth shifts shall be of easier implementation. In this direction, steps of $65°$ were not considered.

Tables III and IV summarize the results for the cell-sweeping settings discussed above. These results support the assumption that faster sweeping speeds optimize the cell-sweeping performance. The throughput enhancements compared to the static deployment decrease as the sweeping period increases. As the sweeping speed becomes slower, the cell-sweeping concept approaches a static deployment. Therefore, the channel variation which is one of the main characteristics exploited by the cell-sweeping design, is lower. Thus, a cell-sweeping configuration of 15º or 35º every TTI combined with PF scheduling policies maximizes the performance of this novel concept. It more than doubles the static sectors performance at the cell-edges (5^{th}-percentile), while significantly increases the average network performance in 35% to 38%. Moreover, data rate gains are also achieved for the cell-centre locations (95^{th}-percentile) when compared to the static deployment. Additionally, irrespective of the configuration, cell-sweeping always presents overall network performance gains which is encouraging and provides some flexibility when envisioning practical deployments and its potential challenges.

This section explored different configurations of the cell-sweeping concept. A discussion was provided alongside the outputs presentation. Irrespective of the applied configuration, cell-sweeping provides consistent benefits for the cell-edge users and overall network. Nonetheless, optimal performance is obtained for high sweeping speeds. This typically stands for a low P (ideally 1 ms), and steps that take better advantage of channel variations. Taking practical aspects into consideration, values of A ranging from 15º to 35º provide a good exploration of channel variation, swapping between typical cell-centre and edge locations in a relatively low number of TTIs.

IV. Towards Energy Efficiency with Cell-Sweeping

One potential benefit of cell-sweeping is related to the network energy efficiency. The previous results showed that optimal cell-sweeping parameter configuration and appropriate scheduling policies lead to performance gains in the overall network. These gains can be used to measure potential energy efficiency benefits arising from cell-sweeping. In this analysis, two different energy efficiency metrics are used. Initially, the energy per bit (J/bit) is evaluated from a transmitted power perspective. Secondly, a BS power consumption model is considered to measure the energy saved with cell-sweeping when reducing the use of physical resource blocks (PRBs).

TABLE III: Cell-sweeping performance compared to the static scenario for different sweeping periods keeping the sweeping amplitude fixed at 15º.

Throughput with Proportional Fair [Mbps]						
Metrics		50 Users / Cell				
		Full Sweep 30 laps				Static
		15º/TTI	15º/10 TTI	15º/30TTI	15º/60TTI	
%ile	5	0.15 +125.5%	0.136 +100%	0.127 +86.8%	0.125 +83.8%	0.068
	50	0.43 +41.6%	0.347 +14.1%	0.329 +8.2%	0.319 +7.1%	0.304
	95	0.86 +20.5%	0.852 +19.2%	0.833 +16.5%	0.877 +9.4%	0.715
Average		0.46 +35.2%	0.413 +21.1%	0.396 +16.1%	0.39 +10.7%	0.341

TABLE IV: Cell-sweeping performance compared to the static scenario for different sweeping periods keeping the sweeping amplitude fixed at 35º.

Throughput with Proportional Fair [Mbps]						
Metrics		50 Users / Cell				
		Full Sweep 30 laps				Static
		35º/TTI	35º/10 TTI	35º/30TTI	35º/60TTI	
%ile	5	0.153 +130%	0.147 +116.2%	0.134 +97.1%	0.129 +89.7%	0.068
	50	0.44 +44.5%	0.376 +23.7%	0.347 +14%	0.329 +8.2%	0.304
	95	0.874 +22.3%	0.873 +22.1%	0.84 +17.5%	0.843 +17.9%	0.715
Average		0.472 +38.2%	0.441 +29.3%	0.412 +20.8%	0.395 +15.8%	0.341

A. Radiated Energy Per Received Bit with Cell-Sweeping

The radiated energy per bit is measured as the quotient of the total amount of energy assigned to a UE during a time interval, and the number of bits transmitted in that same period. The total energy is measured considering the power associated to each of the PRBs assigned to the user. Each PRB carries the same power which results from equally dividing the transmitted or radiated power through all available PRBs in the system. This metric can be used to estimate the transmitted power reduction that can be achieved with cell-sweeping to obtain a similar performance to the static deployment. Table V summarizes these results considering the maximized performance gains of PF scheduling policies and the cell-sweeping optimal configuration parameters of $15°$/ TTI and $35°$/TTI.

The gains in throughput provided by the cell-sweeping mean that the energy per bit will be lower since more bits are transmitted for the same transmitted power. The results in Table V show that the energy per bit is reduced by more than 58% in the cell-edge locations, and these gains are propagated to the entire network with an average saving of approximately 50%. Thus, cell-sweeping allows to reduce the transmitted power while keeping the same Quality of Service (QoS) in the network. The 58% less energy per bit used by

TABLE V: Cell-sweeping radiated energy per bit measurement compared to the conventional static deployment.

Radiated Energy Per Bit [J/bit]				
Metrics		50 Users / Cell		
		Full Sweep 30 laps		Static
		15º/TTI	35º/TTI	
%ile	5th	0.5E-05 **-58.6%**	0.49E-05 **-59.3%**	1.19E-05
	50th	0.19E-05 **-20.7%**	0.18E-05 **-23.3%**	0.23E-05
	95th	0.1E-05 **-0.2%**	0.1E-05 **-2.5%**	0.1E-05
Average		0.23E-05 **-50%**	0.22E-05 **-51%**	0.45E-05

TABLE VI: Effect on the 5^{th}-percentile received power when reducing the transmitted power by 25%, 30%, and 50% with cell-sweeping and keeping the static sectors configuration unchanged.

Received Power [dBm]			
Metric	Tx Power Reduction	50 Users / Cell	
		Full Sweep 30 laps	Static 46 dBm
		35º/TTI	
5th %tile	25%	-103 **+39.7%**	-104.4
	30%	-103.4 **+26.5%**	
	50%	-104.2 **+4.5%**	

the cell-sweeping at the cell-edge for a similar performance compared to the static deployments, can be translated into approximately half of the necessary transmitted power. Table VI shows the 5^{th}-percentile performance of cell-sweeping in terms of received power when applying a reduction of 25%, 30%, and 50% of the transmitted power. The comparison is conducted considering the static scenario from previous results, *i.e.*, transmitted power of 46 dBm. The 5^{th}-percentile of the received power is higher with cell-sweeping even if the transmitted power is reduced by 50%. These results show that the cell-sweeping needs lower transmitted power to match the traditional cell deployment performance and supports the energy per bit minimization observed in Table V.

B. Power Consumption Effect of Reducing PRBs Use with Cell-Sweeping

The results presented in section III show significant throughput performance improvement when considering cell-sweeping with appropriate sweeping parameters tuning together with the PF scheduler. These results were obtained for the same available radio resources in both cell-sweeping and static deployments. In this direction, one can reduce the radio resources used with cell-sweeping up to a point where it matches the traditional cell deployment performance. Afterward, a measurement of the energy consumption difference for a similar performance in both deployments but using fewer radio resources with sweeping can be computed. In this direction, the power consumption model from [13] that provides an estimation of the energy consumption per BS cell based on the used radio resources is considered.

The BS power consumption model consists of a linear regression method with mixed effects. It provides a multi-technology process to estimate the energy consumption of a radio and baseband equipment based on the used radio resources. The authors of [13] concluded that one of the main factors influencing the power consumption of a BS is related to the radio resources use which is directly impacted by the number of users, *i.e.*, data traffic. Therefore, the power consumption can be described as a function of the traffic and respective involved PRBs. This model was calibrated based on real LTE network measurements, for typical 800 MHz, 1800 MHz, and 2600 MHz LTE carriers, in urban scenarios. Taking the comparison between the cell-sweeping and a traditional deployment into consideration, the model was calibrated to estimate the variation of the consumed power based on the use of PRBs. This is achieved according to the following expression:

$$Power\ Consumption\ [W] = 119.905 + R * 1.376 \qquad (6)$$

where R is the number of used PRBs.

The cell-sweeping and static scenarios were ran in the simulator for the different available bandwidths in LTE, *i.e.*, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz, with 15, 25, 50, 75, and 100 available PRBs, respectively. The available radio resources were successively decreased with cell-sweeping in each bandwidth until the performance matches the static cell deployment. This match was evaluated considering different performance thresholds defined by the 5^{th}-percentile, average, and 95^{th}-percentile of the user throughput. The results of the described process are presented in Figure 5. It shows the number of PRBs that do not need to be used with cell-sweeping, to achieve a similar performance compared to a conventional deployment that uses all the available PRBs. The major gains are achieved when the performance threshold is the 5^{th}-percentile since it is where the cell-sweeping provides the biggest improvements. Nonetheless, the sweeping system matches the conventional deployment on the average and 95^{th}-percentile with a substantial lower number of PRBs of approximately 20% and 15%, respectively. Applying this PRBs reduction in the power consumption model from (6) translates the results into energy consumption savings, as presented in Figure 6. These results follow the trend observed in the PRBs reduction. Depending on the available bandwidth, the consumed power per cell decreases between 8% and 26.5% when matching the conventional 5^{th}-percentile user throughput performance, and approximately 4% to 11% and 3% to 8% for the average and 95^{th}-percentile, respectively.

V. Conclusions

The novel cell-sweeping concept is proposed as a new cell deployment method to address the inherent network coverage imbalance of mobile networks. Fundamentally, it is designed to improve and overcome the typical network performance degradation at the cell-edge. This is achieved as the wideband SINR analysis suggests, with a 5^{th}-percentile gain of 2.2 dB and a uniform SINR distribution for all locations around the site. Furthermore, when appropriate scheduling policies are in place, the gains can be extended to the entire network, including optimized performance for the average and 95^{th}-percentile user throughput. The analysis of the cell-sweeping configuration parameters A and P showed that higher sweeping speeds

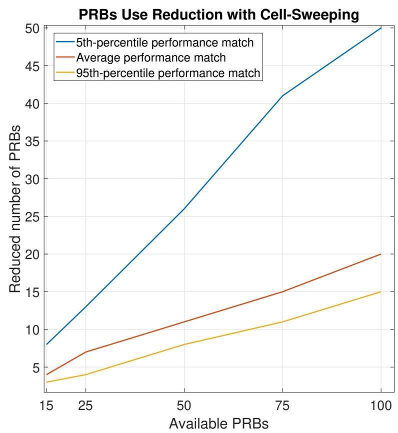

Fig. 5: Reduction of the number of PRBs with cell-sweeping for similar performance to the static cell deployment.

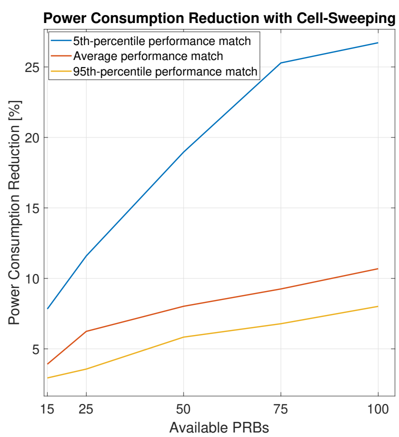

Fig. 6: Power consumption reduction per cell with cell-sweeping based on lower radio resources use.

favour the cell-sweeping operation since the concept takes advantage of higher radio channel fluctuations. In this analysis, $15°/\text{TTI}$ and $35°/\text{TTI}$ maximized the concept performance. Moreover, it was shown that irrespective of the configuration parameters selection, cell-sweeping always provided gains to the overall network.

In the final section, the energy efficiency use case with cell-sweeping was explored. It was shown that the cell-sweeping takes lower energy per bit since it enhances the network throughput without increasing the input power. Therefore, it requires less power to perform at the same level as the static cell deployment. This was validated in a first instance by reducing the transmitted power. Cell-sweeping allows a reduction of up to 50% of the transmitted power without losing performance at the 5^{th}-percentile received power when compared to the static deployment with the original 46 dBm transmitted power setting. A study on the BS energy consumption was also carried out involving a power consumption model based on real network analysis. Considering a reduction of the radio resources and its associated power consumption, it was concluded that the cell-sweeping uses up to 50%, 20%, and 15% less power to achieve the same 5^{th}-percentile, average, and 95^{th}-percentile user throughput performance, respectively, than the conventional cell deployments.

Further optimization of the cell-sweeping parameters in different environments / channels / user speeds, to study and estimate the potential extension in coverage area and possible reduction in BS deployments for the same coverage quality will be exploited in the future iterations of this concept. Additionally, the cell sweeping presents some challenges that need investigation. The increased handover rate due to the sweeping nature of the concept, and practical implementation aspects are being studied. Preliminary analysis show that increased handover and associated increase in signalling is expected to be mitigated with the partial sweeping deployment. This configuration limits the sector sweeping to a certain range of the horizontal plane which considerably attenuates the handover rate. Detailed explanation and deep analysis of these challenges and respective solutions are being investigated.

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