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Top Challenges in 5G Densification

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Abstract. The current report attempts to explore the top challenges that the MNOs need to overcome during 5G deployment in highly dense populated areas. Indicatively, the MNOs are warned about site acquisition challenges and electrification/energy related needs for a huge number of sites that shall be installed discretely at street level, the demand for rigorous testing and measurements to ensure full network coverage and always-on operation so that even mission critical applications (such as automotive and e-health apps) are enabled, accompanied by associated cost factors. Provided that at the time of writing (beg/2021) little is the worldwide experience from operating 5G networks, potential actions are suggested towards a smooth and efficient short time-to-market 5G deployment. In addition, indicative 5G densification related figures (e.g. amount of h/w nodes and distances among them), are calculated based on a specific FiWi PtMP network solution aiming at supporting the ultra-broadband 5G NR fronthaul bandwidth, while alleviating the need to install fiber terminations at every Base Station site.

Keywords: 5G densification, MNOs, challenges, network dimensioning tool, traffic estimation tool, 5G-PHOS use cases, distance between 5G-PHOS elements.

1 Introduction

The 5G technology requires significant transformations of the legacy networks towards service-driven and highly dense network deployments bringing along various challenges for the Mobile Network Operators (MNOs), not only technical but also business and cost related ones. Since 5G nationwide networks will be gradually deployed, the MNOs shall consider all types of geographical areas, in conjunction with the traffic demand, the service requirements of the 5G services (eMBB, mMTC/mIoT, URLLC) and the network operation services that shall be supported. In particular, in urban, dense urban and hotspot environments, high traffic density and capacity needs are expected, either under normal daily conditions or

occasionally/periodically, during crowded events or with seasonality based activity (e.g., touristic areas). The 5G network densification, that is, the deployment of the 5G access nodes in very short distances among them, constitutes a big challenge for the telecom operators. The densification of the 5G network will be realized with very low-powered (operating in licensed and unlicensed spectrum) radio access nodes and tiny antennas, compared to those of the previous mobile technology generations, and much smaller cells of few meter range, to satisfy the traffic demand and the stringent QoS requirements. The 5G small cells will be deployed at street level, attached to bus stops, outdoor advertising, traffic lights, information kiosks billboards, utility poles, the sides of buildings, etc. How many 5G access nodes are required to support the multitude of the 5G innovative application and services in a residential or a business area of a big European city, or in case of a stadium during a crowded athletic event or a concert? How close to each other do these nodes have to be installed? What about the suitability of their location in terms of power supply and the total energy needs? The above are only indicative problems that the MNOs will face, and they certainly depend on the traffic demand and the technology solutions to be adopted, while currently, little experience from actual dense 5G deployment can be shared. Inspired by the 5G-PHOS project [1], a Phase-2 5G-PPP project that deals with 5G densification issues, the current report attempts to investigate the top challenges¹ that the MNOs need to overcome during 5G deployment in dense urban/hotspot areas efficiently.

The paper is organized as follows: After the introduction, a list of the currently most predominant challenges for the telecom operators concerning the 5G network densification is presented and discussed, followed by potential hints and mitigation activities to be considered proactively. The next section provides an overview of the 5G-PHOS solution followed by indicative 5G-PHOS specific 5G densification figures, for various scenarios in dense, ultra-dense and hotspot environments and for three future timeslots. Finally, conclusions are drawn at the end.

2 Telecom Operators' Challenges associated with 5G Densification

(a) Site acquisition at street level (including power supply and transport capabilities) and licensing

The acquisition of a huge number of 5G sites -ideally power enabled and/or with fiber connectivity- is critical for the competitiveness of the MNOs, since it implies high rental costs and can affect the time-to-market and the offered QoS/QoE.

¹ Challenges related to network technologies and operation (network orchestration, slicing, NFV/SDN, synchronization issues, beam verification, service continuity/handovers, security, etc.), and service provisioning QoS/QoE (latency, bitrates, etc.), are considered beyond the scope of this study since they will be addressed by the technology itself.

Site acquisition is a time-consuming, complex and resource-intensive task. MNOs could accelerate 5G network rollout by establishing new frame agreements with site owners, e.g. municipalities, transport, energy/grid and road operators and individuals incl. incentives (if possible) while achieving rental costs reduction and resolving power and transport issues. In this content, the 5G deployment in densely populated areas, can be facilitated by the Art.57 of the European Electronic Communications Code [24], with administrative charges only. For example, in 2017 TIM and the Municipality of Turin signed a 3-year Memorandum of Understanding to cooperate for making Turin a leading 5G enabled Smart City, to promote the joint development of digital solutions and the deployment of innovative applications. In any case, the MNOs shall (i) capitalize on own or rent assets (2G/3G/4G sites, xDSL/NGA cabinets, buildings, shops); thus, fixed telephony service providers being favored, and (ii) pursue frame agreements with other MNOs on infrastructure sharing (on street-level furniture, rooftop RRHs, fiber infrastructure, power/energy, fronthaul/backhaul, etc.) [5]. In case of fiber connectivity, the Dense WDM equipment (either mounted behind the radio unit or in a hole under the site) shall be considered [4].

(b) Aesthetic impact and other social/public issues

Especially when it comes to highly dense deployment, the visual impact of the new equipment should be minimal in order to appease environmental and public concerns, while at the same time the equipment must be compact and flexible to support a wide variety of innovative but demanding services (smart city and V2X applications, mobile connectivity everywhere, etc.), without compromising performance and efficiency.

Sleek size factors may also mitigate construction works to speed up the 5G installation in highly dense areas. In addition, small and light weight equipment could be integrated in existing constructions, such as lighting poles, traffic lights or underground sites, like the Ericsson's "zero sites", "street furniture sites" and "vault sites" solutions [10]. Such solutions could prove attractive for site owners or utilities so as to proceed with the desired frame agreements with mutual benefits for the involved parties (e.g., a municipality could improve the lighting of an area), while preventing vandalism activities by efficient and not provocative camouflage. To further avoid such incidents and behaviors attributed to health concerns about EM radiation and COVID-19 due to public misinformation [25],[26], as well as to address the reluctance of a number of cities to allow dense network deployment, the MNOs must be prepared, leverage previous experience and proactively raise awareness of the public through campaigns (YouTube videos, advertisements, posts at social media, etc.), on: (a) the 5G benefits and (b) the highly strict and extremely low EM limits set by the Intern'l Commission on Non-Ionizing Radiation Protection (ICNIRP); in practice, 10 to 50 times lower than the emission levels where health effects may start. Noted here that an updated version of ICNIRP indications has been published; to be considered in Council Recommendation 1999/519/EC [23], [24].

(c) Energy consumption demand (and Energy Optimization)

The energy consumption in 5G networks, strongly associated with the traffic demand rise, significantly exceeds that of the LTE networks by 2-5 or 3 ½ times ([11], [12]) and is indeed a major issue in the few real 5G deployments [13]. It is critical that the energy does not follow the traffic rise [9], especially in highly dense areas where exponential 5G traffic increase is expected, while one of the 5G-PPP key targets is saving up to 90% of energy per service provided [14]. Recent studies show that 5G networks are up to 90% more energy efficient per traffic unit than any previous wireless technology generation, but the overall network energy will rise dramatically ([16],[17]), although not identifiable yet. Besides the traffic explosion, the power usage increase in the overall 5G network is mostly attributed to the RAN due to: denser deployments, new power-hungry components, including microwave or mm-wave transceivers, faster data converters, high-power/low-noise amplifiers, field-programmable gate arrays (FPGAs) or Application-Specific Integrated Circuits (ASICs), MIMO antennas, as well as edge compute facilities for local processing to support low-latency applications and IoT [13].

The goal of decreasing energy consumption in the telecommunications sector has led the researchers and the industry to focus on energy-saving features in the radio base station and network levels, such as peak shaving, voltage boosting, energy storage, artificial intelligence (AI) and machine learning (ML) techniques, as well as new 5G architectures and protocols. Additionally, practices that are up to the MNOs to adopt include: (i) Selecting low power access network solutions, green powered (by solar panels, batteries, etc.) and supporting energy-saving features [19]; (ii) network intelligence, e.g. power-off gNBs when no traffic is available; (iii) capitalization on existing assets/sites; (iv) infrastructure sharing among MNOs (at gNB/fronthaul/ backhaul level); (v) exploration of optimal energy consumption deployments ([15],[18]) through area specific studies and network measurements.

(d) Service continuity related to power issues

Another great challenge for the MNOs is to ensure electrification (e.g. access to different sources/means) and seamless power supply (incl. redundancy) of the 5G dense/ultra-dense network deployments so that 24x7 service continuity (at street level) is enabled to support specific, critical services, e.g. automotive related ones.

To ensure always-on connectivity, batteries/generators (super-capacitor to cover micro interruptions and lithium batteries to cover long blackouts) seem to be mandatory. In cases of local powering solutions, in addition to the AC connection cost per site, cost and efficiency must be carefully considered since a huge number of solar panels, AC/DC converters and batteries will be required. Remote powering also exhibits advantages, such as the centralized connection to AC grid, redundancy concepts realization, centralized backup and associated cost reduction, introduction of power line duplication or power rings. For example, in cases of fiber connectivity availability, the utilization of Low Voltage DC (LVDC) technology (up to 400VDC for TLC/ICT applications) in the primary distribution segment and the usage of Safety Extra Low Voltage (SELV) DC to feed directly the equipment could be an option ([6],[7],[8]). Obviously, a monitoring/ management system shall enable

awareness of the power network status in real-time and performing appropriate maintenance activity.

Integration/maximization of renewable energy apart from greening the cellular networks and leading to OPEX reduction, it will also limit the peak on-grid energy consumption, ensuring service continuity in case of grid failure. Extra accumulated energy managed by a smart controller, without however compromising service continuity, could feed the grid.

(e) Increased network planning, deployment and optimization complexity

The extremely low electromagnetic limits in conjunction with the high density of low-powered gNB/access nodes, the introduction of mm-wave technologies, the frequency chunks' availability, the refarming, the technology alternatives for fronthaul and backhaul, the intensively variable radio environment, make access network planning and deployment very challenging or even impossible in some cases ([15],[16]), while interference and total spatial electromagnetic power must be kept at minimum, which becomes even harder, if the acquisition of the optimal locations as indicated by the planning tools may not be possible.

To overcome all these planning/deployment complexity factors and guarantee 5G offerings at the desired high QoS/QoE especially in dense 5G deployments, continuous network and traffic monitoring is required, more accurate planning tools shall be used, while huge optimization effort for long(er) periods of testing (coverage, interference, throughput, latency, handovers, dropped calls, etc.) and fine tuning/troubleshooting activities must be conducted by the MNOs. Regarding the transport network, various converging technologies shall be selected capable of supporting deployment flexibility and scalability, by taking into account various factors such as area specifics, technologies' deployment feasibility, traffic/usage forecasts, long-term services roadmaps, as well as the implicated costs.

(f) Spectrum related issues

5G utilizes different parts of the radio spectrum to deliver performance, capacity and coverage [22]. Spectrum resources allocation and management constitute a primary challenge. Despite the advancements in access network (e.g., massive MIMO, scheduling and signal processing techniques) which contribute to the efficient usage of spectrum resources, large chunks of spectrum will still be needed (see 66–71 GHz and 40.5-43.5 GHz allocations) for dense small cell networks. At the same time, to satisfy the coverage and capacity requirements for wide areas, low frequency bands currently allocated for nationwide mobile network deployments will be needed; thus rendering refarming (and related investment on new frequency license acquisition) a huge challenge for MNOs.

(g) Huge CAPEX and OPEX

The deployment of 5G networks will require CAPEX and OPEX investments on 5G (frequency) license, new equipment/hardware, site rental, energy, backhaul and civil works, network equipment operation and maintenance, sophisticated

monitoring and optimization tools, as well as trained and skillful engineers ([3]). To pursue reduction of the costs especially related to the increasingly complicated, distributed, ultra-dense 5G network deployments, without compromising the offered QoS/QoE, the MNOs shall: (i) conduct realistic techno-economic studies (with different deployment scenarios, critical radio parameters, alternative technologies, etc.); (ii) spend huge effort on network optimization; (iii) select flexible, energy/cost efficient, future proof solutions, (iv) shutdown previous generation networks (e.g., 3G); (v) adopt best site acquisition and energy strategy (see (a), (c), etc.). Concerning the electricity cost, it is expected to rise dramatically accounting for 15-20% of the total OPEX [13]. Indicatively, China Mobile, one of the leading 5G mobile operators is seeking subsidies from the Chinese government to be able to afford it.

3 5G-PHOS solution overview

5G-PHOS, a Phase-2 5G-PPP project attempts to address, in a flexible and efficient way, the challenging 5G densification framework to support the demanding coverage and capacity requirements of urban, dense urban and hotspot environments at any time and under any circumstances, along with the wide variety of 5G services. In this context, the 5G-PHOS project proposes an ultra-broadband converged FiWi PtMP fronthaul network, capable of supporting the required 5G NR fronthaul bandwidth, and exhibiting a wide range of benefits [26], including alleviating the need to install fiber terminations at every MNO site, offering fast roll-out and short time-to-market, by replacing or complementing fixed/fiber based solutions. 5G-PHOS solution builds upon the prevalent enhanced eCPRI standard and creates the necessary infrastructure to interconnect eCPRI-capable equipment in a PtMP way, including (Fig.1): the Master and the Slave Flexbox Units, the Rooftop Remote Radio Head (R-RRH) (incl. PCBs), the Secondary Lamppost RRH (SL-RRH) [26].

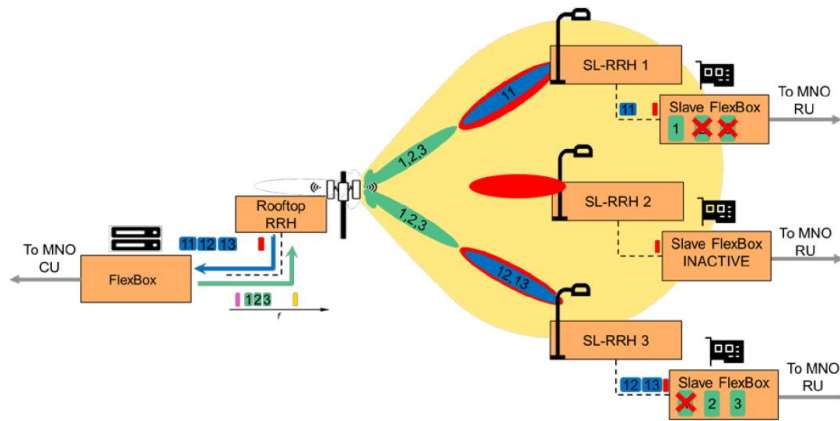


Fig. 1. The 5G-PHOS Architecture

4 5G- PHOS Densification Figures

The aim of this section is to provide indicative deployment configuration instances (amount and inter-distance of H/W components) of the 5G-PHOS solution in three Use Cases envisioned by the 5G-PHOS project and in three “timeslots” (i.e., 2022, 2027, 2032), so that the expected rise in 5G services usage and 5G subscribers can be supported. The Use Cases under study [20] refer to:

1. A Dense area located at the District 15 of Paris (Fig. 2), covering a total area of 2,359,800 m² (2280m x 1035m).
2. An Ultra Dense area located in the vicinity of the Eiffel Tower (Fig. 2) covering a total area of 283,812 m² (804m x 353m).
3. A Hotspot area corresponding to the seats area (18,467 m²) of the Paris Saint-Germain (PSG) FC stadium² (Fig. 3).

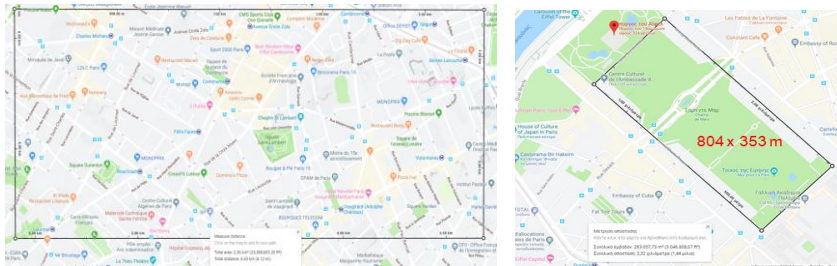


Fig. 2. Dense Area (District 15, Paris) and Ultra-Dense Area (greater area of the Eiffel Tower, Paris)



Fig. 3. Hotspot Area (Paris Saint-Germain FC stadium, Paris)

Dimensioning Methodology

The methodology adopted is based on two fully parameterized tools developed specifically for the 5G-PHOS solution: (i) A traffic tool [20] that calculates the min, max, average and peak offered traffic for a set of input parameters (subscribers,

² <http://www.stadiumguide.com/parcdesprinces/>

concurrent services usage, service and tenants' requirements, etc.); (ii) A dimensioning tool [21] that models the 5G-PHOS architecture, incorporates dimensioning rules and area/UC specific deployment aspects/restrictions and taking into account the offered traffic demand, calculates automatically the (optimal) configuration(s) of 5G-PHOS network deployment (number and inter-distance of R-RRHs, SL-RRHs, PCBs, master and slave Flexbox units) for the (9) cases under study (3 use case scenarios for each of the 3 years).

List of Assumptions

- Worst case (offered) total traffic scenarios per UC [20]: Busy Hour for the Dense UC; a big event, e.g. a concert for the Ultra-Dense and a football match for the Hotspot UCs, for different 5G subscribers' penetration rates and 5G coverage area percentages for the three (3) time periods.
- Dimensioning related / element: R-RRH range/PCB azimuth, PCB throughput, #channels/PCB, #PCBs/Master Flexbox, Master Flexbox throughput, etc.
- Radio related: Max bitrate / SL-RRH, overheads vs. FS (Functional Split), SL-RRH range, etc.
- Number of 5G MNOs: 3 for Dense and Ultra-Dense, 1 for the Hotspot UC.
- Traffic offloading over fiber connected SL-RRHs: 30/20/12% for Y-2022/2027/2032 (in Dense UC), 30% (in Ultra Dense and Hotspot UCs) for all years.
- Area characteristics: perimeter, Km², population density, etc.
- Restrictions: #SL-RRHs that can be connected to a (R-RRH) PCB based on #channels and coverage area, #MNO-RRHs / SL-RRH, etc.

5G-PHOS Densification Figures

Table 1: 5G-PHOS Network Dimensioning/Configuration per UC

Use Case	Dense			Ultra-Dense			Hotspot		
	2022	2027	2032	2022	2027	2032	2022	2027	2032
Traffic (Gb/s)	35	600	2000	60	250	650	90	220	430
5G area coverage	25%	50%	100%	100%	100%	100%	100%	100%	100%
#R-RRHs	8	15	29	13	13	13	10	24	28
#PCBs (Tx+Rx)	114	228	454	48	48	48	20	47	110
#SL-RRHs	57	114	227	24	48	125	29	71	138
#Slave Flexbox	57	114	227	24	48	125	20	71	138
#Master Flexbox	4	7	7	2	2	2	1	1	3
Ave dist. (m) btw SL-RRHs	114	114	114	125	86	55	29	18	11
Ave dist. (m) btw R-RRHs	325	325	325	245	245	245	66	28	24

Evaluation of Results and Generic Remarks

The dimensioning tool calculates (automatically) all valid configurations, taking into account both network coverage and capacity requirements. Although it is 5G-

PHOS specific, given its parameterized, expandable and customizable structure, it could support any 5G solution and any scenario could be potentially investigated. The results are indicative of the order of magnitude for both the amount of the H/W elements and the short distances between them, as well as for the network evolution path. They can also be used as a reference for comparison with other 5G solutions or as input for the investigation of the energy/power consumption of the related network segments. They could be also utilized for 5G-PHOS techno-economic studies, to provide insights for the MNOs' deployment strategy and risks mitigation. Future technology evolution may improve the current densification figures, but nonetheless the initial figures presented here can be employed as a roadmap for estimating costs and initial planning. For more accurate results, a planning tool is considered as more appropriate.

5 Summary

In this paper the MNOs are warned on significant challenges, they have to cope with, related the 5G densification in densely populated areas (e.g., site acquisition, H/W and environmental footprint impacting on the public opinion, energy consumption expected increase, the demand for service continuity, the increased complexity in network planning, deployment, optimization and spectrum allocation, the related cost factors). Hints and recommendations are discussed to support MNOs' competitiveness efficiency and sustainability. In addition, a study on 5G densification is conducted, based on fully parametrized traffic and dimension tools. Although indicative and 5G solution specific, the outcomes provide the order of magnitude of 5G densification figures in dense and hotspot areas over the years, and could further assist MNOs in their deployment strategy, cost and energy savings.

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