Global5G
vision, standardisation & stakeholder engagement in 5G

Project Title	Global vision, standardisation & stakeholder engagement in 5G
Project Acronym	Global5G.org
Grant Agreement No	761816
Instrument	Coordination and Support Action
Topic	Shaping the global 5G PPP vision by strengthening the link between vertical industry, standardisation and research, focusing on potential future investments in 5G, roll-out to market, as well as policy, regulatory, spectrum and legal discussions.
Start Date of Project	01.07.2017
Duration of Project	30 Months
Project Website	www.global5g.org

D3.1 – STUDY ON SMALL CELLS AND DENSE CELLULAR NETWORKS REGULATORY ISSUES

Work Package	WP3, Global 5G ecosystem: standards and support to consensus building
Lead Author (Org)	AALTO
Contributing Author(s) (Org)	Trust-IT Services
Due Date	31.12.2017 (M6)
Date	31.12.2017
Version	1.0

Dissemination Level

X	PU: Public
	PP: Restricted to other programme participants (including the Commission)
	RE: Restricted to a group specified by the consortium (including the Commission)
	CO: Confidential, only for members of the consortium (including the Commission)

The work described in this document has been conducted within the project Global5G.org. This project has received funding from the European Union's Horizon 2020 (H2020) research and innovation programme under the Grant Agreement no 761816. This document does not represent the opinion of the European Union, and the European Union is not responsible for any use that might be made of its content.

Versioning and contribution history

Version	Date	Authors	Notes
0.1	21.08.2017	Edward Mutafungwa (AALTO)	Draft ToC
0.2	08.09.2017	Edward Mutafungwa (AALTO) and Olga R. (Trust-IT)	Revised ToC
0.3	30.09.2017	Edward Mutafungwa (AALTO), Laura Baracchi (Trust-IT Services), Olga Renda (Trust-IT Services), and Giorgio Micheletti (IDC)	Initial report prepared for COCOM WG and integrated to deliverable
0.4	03.11.2017	Edward Mutafungwa (AALTO)	Editing and revisions
0.5	08.12.2017	Edward Mutafungwa (AALTO)	Editing and revisions
0.6	13.12.2017	Edward Mutafungwa (AALTO)	Editing and revisions
0.7	22.12.2017	Laura Baracchi (Trust-IT Services)	Review and comments
0.8	27.12.2017	Edward Mutafungwa (AALTO)	Editing and revisions
0.9	30.12.2017	Edward Mutafungwa (AALTO)	Editing, proof-reading and revisions
1.0	31.12.2017	Edward Mutafungwa (AALTO)	Final corrections

Disclaimer

Global5G.org has received funding from the European Commission's Horizon 2020 research and innovation programme under the Grant Agreement no 761816. The content of this document does not represent the opinion of the European Commission, and the European Commission is not responsible for any use that might be made of such content.

Table of Contents

List of Tables

List of Figures

Executive Summary

This document reports on the Global5G.org study on deployment and regulatory aspects to help EU and its member states identify the most effective way to lower the costs of deploying Small Cells and dense cellular networks.

An overview of small cells is presented to set the scene on the current understanding of small cells and network densification. This also includes recent reporting on current and future small cell deployments trends. The multiple considerations for small cell deployments are to further the understanding of the potential regulatory barriers to their dense deployments.

The small cells diverse deployment scenarios (e.g. urban, enterprise, rural etc.) has implications in terms of the growing variety of stakeholders who may have a stake in (or express concerns about) the increased densification of small cells. This report identifies and the small cell stakeholders and provides an assessment of the positive and/or negative influences on dense small cell deployments.

The regulatory factors influencing dense small cell deployments are analysed, whilst taking into consideration the perspective of different stakeholders and highlighting potential areas of regulatory interventions to facilitate deployment. Specifically the analysis focuses on four key factors: general definition or classification small cells; regulatory implications on sharing of small cells; radio frequency electromagnetic field (RF-EMF) exposure limits; and approvals, licensing and permits for small cell deployments.

Exemplary case studies from four countries are also presented in report to provide anecdotal evidence on some of the barriers to dense small cell deployments (particularly challenges that are not unique to a particular market) and the different approaches taken to overcome these barriers. The cross-case conclusions are then formulated using case study synthesis segmenting the main common theme of the case studies ("*Interventions to facilitate dense small cell deployments*") into a number of themes (collaboration, transparency, consistency, competition and innovations) each with its own conclusions, leveraging at least one case study as an example.

The document concludes with summary findings for industry, research and policymakers, highlighting barriers for small cell deployment, but also showcasing some best practices, which could provide potential models for regulations in line with EU policy priorities, including the Digital Single Market (DSM) and Action Plan for 5G.

Abbreviations

3GPP	Third Generation Partnership Project
5G NR	5G New Radio
5G PPP	5G Public Private Partnership
API	Application Programming Interface
BBU	Baseband Unit
BDAC	Broadband Deployment Advisory Committee
BEREC	Body of European Regulators for Electronic Communications
BS	Base Station
BTS	Base Transceiver Station
CAGR	Compound Annual Growth Rate
CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal and Telecommunications Administrations
COCOM	EU Communications Commission
DAS	Distributed Antenna Systems
DoA	Description of Action
DSL	Digital Subscriber Lines
DSM	Digital Single Market
EECC	European Electronic Communications Code
EIRP	Effective Isotropic Radiated Power
EMEA	Europe Middle East and Africa
EMF	Electromagnetic Field
EAG	Expert Advisory Group
EC	European Commission
eMBB	Enhanced Mobile Broadband
ER	Exposure Ratio
ETSI	European Telecommunications Standards Institute
EU	European Union
E-UTRA	Evolved Universal Terrestrial Radio Access
FCC	Federal Communications Commission
GNI	Gross National Income
GSMA	GSM Association
GWCN	Gateway Core Network
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers

IoT	Internet of Things
ISD	Intersite Distance
IT	Information Technology
KPIs	Key Performance Indicators
KR	Republic of South Korea
LAA	Licensed Assisted Access
LBT	Listen-Before-Talk
LOS	Line of Sight
LSA	Licensed Shared Access
LTE	Long-Term Evolution
LTE-A	LTE-Advanced
MIMO	Multiple Input Multiple Output
MMTC	Massive Machine-Type Communications
MEC	Mobile Edge Computing
MOCN	Multiple Operator Core Network
MORAN	Multiple Operator RAN
NARUC	National Association of Regulatory Utility Commissioners
NBC	National Building Code of India
NEDAS	Northeast DAS & Small Cell Association
NFV	Network Functions Virtualization
nLOS	Near LOS
NRA	National Regulatory Authorities
Ofcom	Office of Communications
PNF	Physical Network Function
PPP	Public Private Partnership
PU	Public (deliverable)
QoS	Quality of Service
RAN	Radio Access Networks
RED	Radio Equipment Directive
RNC	Radio Network Controller
RRH	Remote Radio Head
RSPG	Radio Spectrum Policy Group
R&I	Research & Innovation
SAR	Specific Absorption Rate
SCaaS	Small-cells-as-a-Service
SCF	Small Cell Forum
SDO	Standards Developing Organisation
SDN	Software-Defined Networking

S-GW	Secure Gateway
SINR	Signal to Interference and Noise Ratio
SLA	Service Level Agreement
SME	Small and Medium Enterprise
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCO	Total Cost of Ownership
TDD	Time Division Duplexing
TIA	Telecommunications Infrastructure Association
ToR	Terms of Reference
TRAI	Telecommunications Regulatory Authority of India
UAV	Unmanned Aerial Vehicle
UDN	Ultra Dense Networks
URLLC	Ultra Reliable Low Latency Communications
USO	Universal Service Obligation
VHC	Very High Capacity
VNF	Virtual Network Functions
V2X	Vehicle-to-Everything
WHO	World Health Organisation
WRC	World Radiocommunications Conference

1 Introduction

1.1 Purpose and Scope

This document reports on the Global5G.org study on deployment and regulatory aspects to help EU and its member states identify the most effective way to lower the costs of deploying Small Cells and dense cellular networks. The output of the Global5G.org's study on small cells will serve to highlight barriers for small cell deployment, but also highlight best practices, which could provide potential **models for regulations in line with EU policy priorities, including the DSM and Action Plan for 5G.** The study findings are informed by on inputs from various stakeholders ranging, from industry bodies to stakeholders involved in Phase 2 of the 5G-PPP Infrastructure Public Private Partnership[1]. In this respect Global5G.org is specifically addressing **Action 4 of the "5G for Europe Action Plan":**

> *Action 4 — As part of the development of the 5G national roadmaps,* ***the Commission will work with the industry, the Member States, and other stakeholders*** *to:*
>
> *(..)* ***Identify immediately actionable best practice to increase the consistency of administrative conditions and time frames to facilitate denser cell deployment****, in line with the relevant provisions of the proposed European Electronic Communications Code.*

1.2 Structure of the document

The remainder of Section 1 presents the overall methodology adopted for this study. Otherwise, the rest of the document is divided into the following chapters:

- **Section 2** – Overview of Small Cells: provides general overview of small cells including review of trends and key deployment considerations.
- **Section 3** – Stakeholder Analysis: presents an overview relevant stakeholders and assesses the concerns and interests of different stakeholders
- **Section 4** – Regulatory Factors Impacting Dense Small Cell Deployments : presents and discusses the key regulatory factors or issues that impact dense small deployment and operation.
- **Section 5** – Exemplary Country Case Studies: presents exemplary case studies that provide insights from realistic deployment challenges and interventions in selected case study countries
- **Section 6** – Summary Study Findings and Conclusions: summarises the study findings for each regulatory factor or issue.
- **Section 7** – References
- **Section 8** – Definition of the terms used in the report; presents a glossary table of some of the key terms appearing in the report.
- **Section 9 onwards** – The Appendices.

[1] https://5g-ppp.eu/

1.3 Overall methodology

1.3.1 Information and data gathering methods

This study is informed by facts and opinions from a wide range of sources, both within and outside the traditional mobile industry. The gathering of the necessary study information and data is implemented through desk research, questionnaires and the engagement of relevant stakeholders and experts. These processes or tools are described briefly below.

1.3.1.1 Desk research

The increased importance of small cells and early experiences from small cell deployment projects has generated a wide range of documentation and news items. These resources constitute a significant part of the knowledge compiled in this study. Therefore, a desk research approach is intensively undertook to gather information from sources including, but not limited to, research publications, analytical reports, stakeholder reports, standardisation documents, regulatory and policy documents, open data repositories, news articles, press releases and blog posts. A deliberate effort is made to ensure that the information gathered is balanced, to understand the contexts of the arguments both for and against network densification and to present different perspectives related to tighter or looser regulations, and incentives. Moreover, the desk research also includes cross-referencing and the collation of the gathered information.

1.3.1.2 Questionnaires

This study is one which seeks to have a broad understanding of the regulatory issues for small cell deployments, not just across different stakeholder groups but also the perspective of stakeholders from different countries (EU member states and beyond). To that end, the use of the questionnaire provides means for gathering both qualitative and quantitative information for the purposes of understanding and testing the hypothesis of this study. The primary target of the questionnaires are the national or local authorities responsible for developing rules and regulations, as well as, providing permits for small cell deployment in respective countries. To that end, part of this work is organised in conjunction with study for the EU Communications Commission (COCOM)[2], Working Group 5G. The role of Global5G in study titled "*Facilitation of denser cell deployment*"[3] has been to update COCOM on recent developments and coordinate a questionnaire to Member States represented in COCOM.

1.3.1.3 Stakeholder and expert engagement

The understanding of the regulatory aspects of small cells deployments is also enriched by first-hand knowledge, experiences or insights of the stakeholders and experts involved with small cell technology development and/or deployment. Several discussions and interviews were conducted (mostly online) with stakeholders and experts. These engagements are typically semi-structured and to some extent tailored to the area of the organisational role or expertise of the engaged party.

1.3.2 Stakeholder analysis

Stakeholder analysis is utilised in many disciplines and as such, the term 'stakeholder analysis' has acquired an equally diverse range of definitions. Generally, stakeholder analysis refers to the process of identifying and subsequently developing an understanding of the different perspectives of the entities (stakeholders) that are involved in or possibly affected by a trend, project, programme, regulation, policy or any other proposition. Stakeholder analysis entails the **consideration and balancing of the competing demands of the different stakeholders**, especially the most critical constituencies. To that end, stakeholder analysis is considered a systematic process of gathering,

[2] The COCOM is a committee composed of representatives of EU Member States. Its main role is to provide an opinion on the draft measures that the Commission intends to adopt. https://ec.europa.eu/digital-single-market/en/communications-committee
[3] The report of the COCOM still will published in first quarter of 2018

analysing and synthesising information (both qualitative and quantitative) to determine the concerns, interests and dispositions of different stakeholders. These would then provide means for conceptualising, designing or implementing of new ideas, regulations, policies, programmes or other interventions. Ultimately, the benefit of stakeholder analysis is that it provides an avenue to pinpoint the possibilities and mechanisms to influence other stakeholders, as well as, ensure that propositions put forward do not result in interests of one particular stakeholder overriding those of the other stakeholder(s) [Fletcher2017].

In the context of this study, the increased density of small cell deployments creates a need for installing small cells in wider range of areas. Whereas, previously mobile operators would only deploy their base stations on a limited number of outdoor sites acquired by the operator, the dense small cell deployments will occur in a much larger number of sites (both outdoor and indoor) that are mostly owned by third-parties. This increases the diversity of stakeholders in network infrastructure deployment and further complicates the balancing of the interests of different stakeholders to ensure small cells deployment for network densification. Therefore, a stakeholder analysis is a useful process to understand how the different small cells stakeholders could be involved with or impacted by the various regulatory aspects that may incentivise or complicate the dense deployment of small cells. Accordingly, we approach the strategic analysis by utilising the descriptive conceptual framework illustrated in Figure 1.

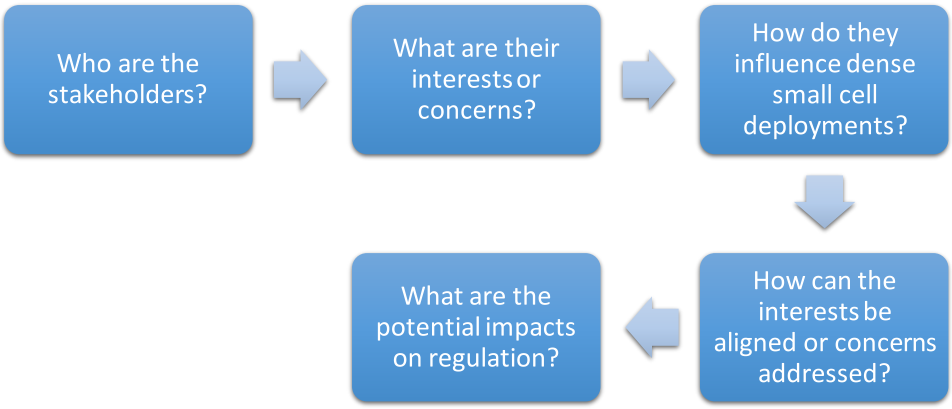


Figure 1 Conceptual framework of the stakeholder analysis

1.3.3 Case study approach

Case study methods are employed here as a supplementary research approach to provide additional context to the literature surveys, stakeholder analysis and other research activities in this study. All of these research methods have certain benefits and limitations, depending on three conditions: type of research question (or study objective); the control that the researcher has over events; and the focus on contemporary as opposed to historical phenomena. To that end, case studies are the preferred research method when [Yin2009]:

1) Questions of “how” and “why” are being posed,

2) The researcher has little control over events,

3) The focus is on contemporary phenomena within real-life contexts.

It is indeed noted that the methods described previously focus on explorative “who, what, where, how many, how much?” line of inquiry needed to describe a prevalence of a phenomena (e.g. barriers to small cell deployment). Whereas, a history or case studies focus on “how” and “why” because such questions address operational links needing to be traced over time, rather than mere frequencies or incidence [Yin2009]. For instance, to find out how a specific country overcame a certain obstacle for installing in-building small cells, it would be less suitable to utilise a survey but rather conduct a history or case study. Exemplary questions that could be used to select the case studies in this report are:

- ***How does an administrative process, rule or regulation X presents a barrier to dense deployment of small cells in country Y?***
- ***What was the policy or regulatory intervention in country Y that was taken to facilitate dense deployment of small cells in country Y?***

The parameters that determine the case study design are the case itself (e.g. increased small cell deployments because of regulatory intervention X) and the context of the case study (country). The two main case study design categories are single-case design and multiple-case design (see Figure 2) [Yin2009]. The case study design adopted in this study is a multiple-case design, due to need to explore cases in different countries (both within and outside Europe) and consider diverse cases (e.g. different regulatory barriers or interventions), thus providing a broader showcase of important lessons or best practice.

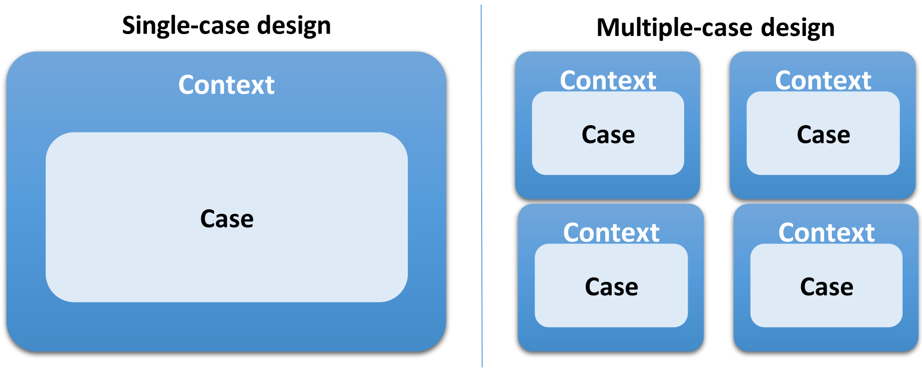


Figure 2 Case study design options

The overall case study workflow is illustrated in Figure 3. The individual case studies (and contexts) are selected based on some distinct attribute in how they address the case study questions. The universality of the small cell deployment challenges makes it useful to include both case studies from within and outside Europe. The case studies are conducted in parallel and the reports for each briefly provided in Section 5, before drawing some cross-case conclusions.

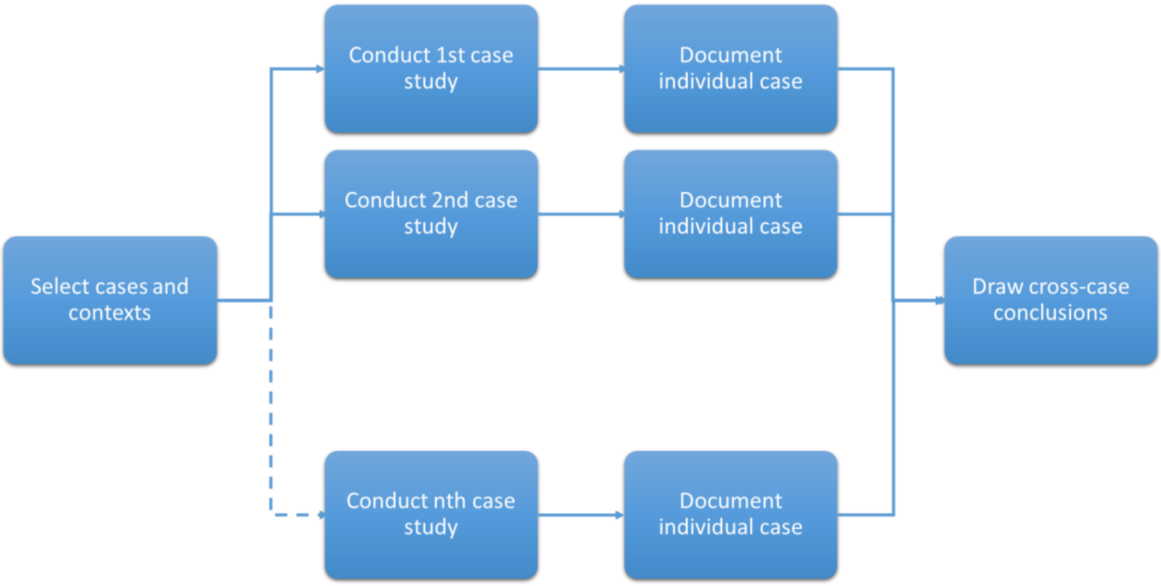


Figure 3 Case study workflow

2 Overview of Small Cells

2.1 Background and motivation for small cells

2.1.1 General definition

The Small Cells Forum (SCF) defines small cells as [SCF2012]: "*an **umbrella term** for operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi. Small cells typically have a range from 10 meters to several hundred metres.*

Legacy mobile networks are dominated by macrocells, which are large cells, typically mounted on a mast or roof top in cities and towns, alongside motorways or on rural hills. Macrocells have radio coverage range of a few kilometres to tens of kilometres and are served by a high-powered cellular base station. However, the 1000x scaling in mobile data traffic volumes over the current decade has obliged operators to upgrade their network capacity. To that end, one of the most effective approaches is to enhance the spatial reuse of limited spectrum through dense deployment of small cells to complement existing macrocellular networks (see example depiction of Figure 4).

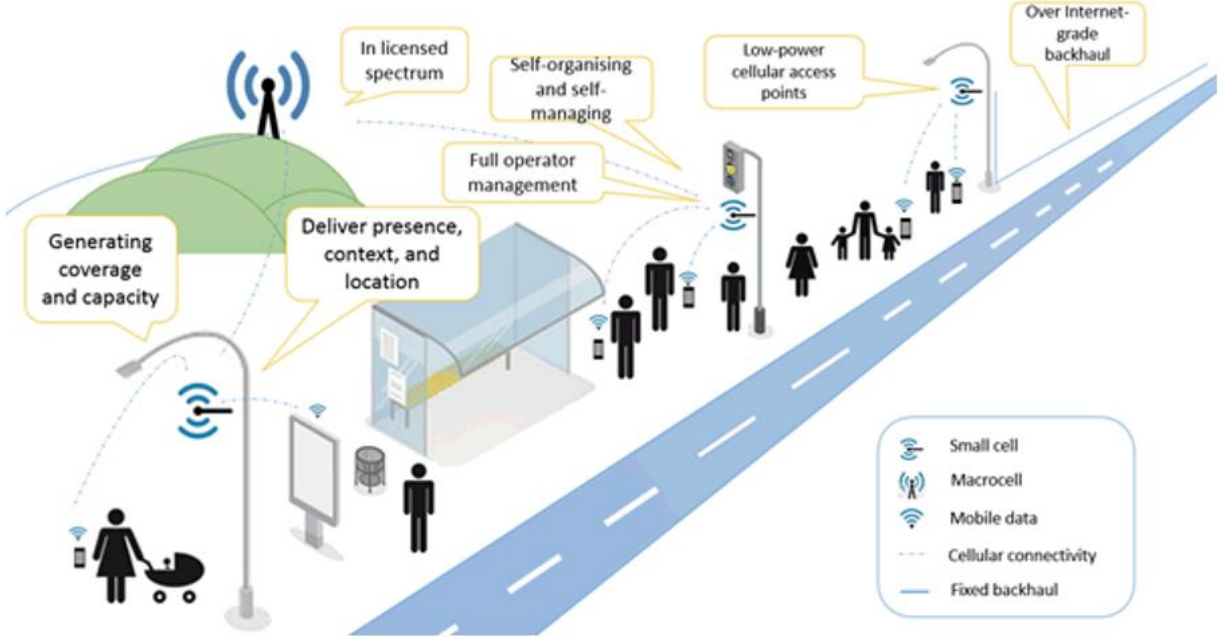


Figure 4 Heterogeneous deployment of small cells and macrocells (Source: [Collier2016])

Various small cells product types exist generally depending on, among other attributes, their targeted coverage range (transmit power) and provided capacity. These small cell variants include (but are not limited to) femtocells, picocells and microcells/metrocells – broadly increasing in cell range from femtocells (the smallest) to metrocells (the largest) as summarised in Table 2. These different small cell labels have been widely in numerous technical literature, marketing materials and so on, with equally diverse interpretations on the mapping of small cells to this typology. Therefore, for sake of generality, this report will in most cases utilise the umbrella term 'small cells'.

Table 1 Types of small cells [SCF2012]

Type	Description
Femtocells	A low-power, short range, self-contained small cells. Initially used to describe consumer small cell units intended for residential homes, the term has expanded to encompass higher capacity units for enterprise, rural and metropolitan areas.
Picocells	Typically used to describe low power compact base stations, used in enterprise or public indoor areas, the term is sometimes used to encompass outdoor small cells as well.
Microcells	Typically used to describe an outdoor short-range base station aimed at enhancing coverage for both indoor and outdoor users where macro coverage is insufficient. Occasionally installed indoors to provide coverage and capacity in areas above the scope of a picocell.
Metrocells	A recent term used to describe small cell technologies designed for high capacity metropolitan areas. Such devices are typically installed on building walls or street furniture (e.g. lampposts). This category can include technologies such as femtocells, picocells and microcells where they meet these deployment criteria.

The small cells can also be categorised according to their access model, namely: closed access, open access and hybrid access [SCF2017]. These models are described briefly below.

- *Closed access small cells*: Small cells whose use is restricted to the owner (e.g. of a private residential small cell) and a limited list of allowed mobile subscribers held in a whitelist. This access model prevents usage of cell resources or potential abuse by uninvited or unknown users in the small cell coverage area.
- *Open access small cells*: This the most common access model, whereby, a small cell deployed by a mobile operator or leased from a thirty party is accessible to all subscribers of the operator. This access model is typically utilised in enterprise space (e.g. shopping malls) and public outdoor small cell deployments.
- *Hybrid access small cells*: This hybrid model combines the benefits of the two other model, creating for instance, new business models, whereby, private small cells become available for use (e.g. during low network load conditions) for subscribers not in the whitelist.

2.1.2 Drivers for dense small cell deployment

Mobile network operators face the continuous challenge of upgrading their networks in response to ever-growing traffic volumes. There is an increase in average traffic consumption per user mostly attributed to the increased adoption of smart devices (e.g., smartphones, mobile virtual reality platforms etc.) and bandwidth-intensive services (e.g. 4K/8K video streaming).

A tenfold increase in average monthly data consumption per subscriber from the 2-5 GB/month in 2016 to 20-50 GB/month is foreseen by 2020 [Nokia2016]. Moreover, the average year-on-year mobile subscriber growths of 5%-15% is expected to continue into the next decade (see Figure 5), with mobile broadband subscriptions constituting 95% of the personal mobile subscriptions in year 2023 [Ericsson2017]. At the same time, subscribers' expectations on service quality also continue to increase, with uninterrupted high-speed connectivity becoming the baseline requirement for most users, regardless of their location or network load conditions.

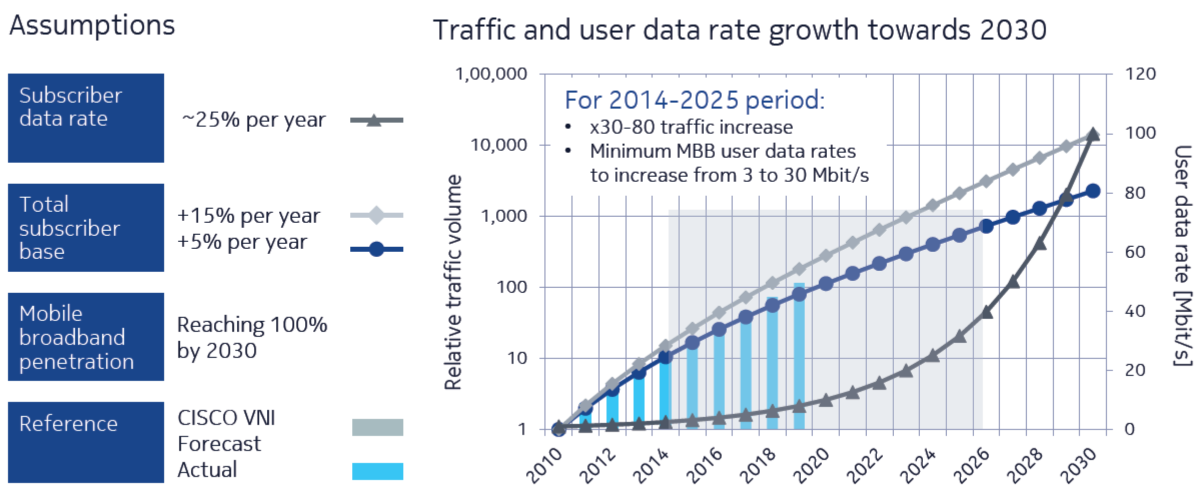


Figure 5 Projection for global mobile traffic growth until 2030[4] [Nokia2016]

In view of this traffic growth, mobile operators may upgrade their networks to radio technologies providing higher network capacities and user throughputs. A currently common scenario is for operators to maintain multi-standard radio access networks that include fourth-generation (4G) Long Term Evolution (LTE) standard and preceding technology generations. These operators are now evolving their LTE network (to LTE-Advanced and LTE-Advanced Pro), which will provide capacity scalability due to increased spectral efficiency in existing bands (through higher order modulation and multi-antenna techniques) and aggregation of a larger number of carrier bands (both licensed and unlicensed). As a result, LTE was already expected to be the dominant standard by end of 2017, with population coverage expected to reach 85% by 2023 [Ericsson2017].

Even as LTE expansion is ongoing, mobile operators, equipment vendors and other industry stakeholders are already aggressively developing and trailing the **fifth generation (5G) network technologies**, which will support continued connectivity needs for next decade and beyond [Qualcomm2017]. To that end, 5G is envisioned to be a unifying connectivity fabric that will connect virtually everything around us — from enabling enhanced mobile broadband services and mission-critical communications to connecting the massive Internet of Things (IoT) — as well as support for use cases yet to be envisioned today (see Figure 6).

[4] The 5% and 15% yearly subscriber growth are shown in the two curves The 2010-2013 data are measured data in Nokia Networks.

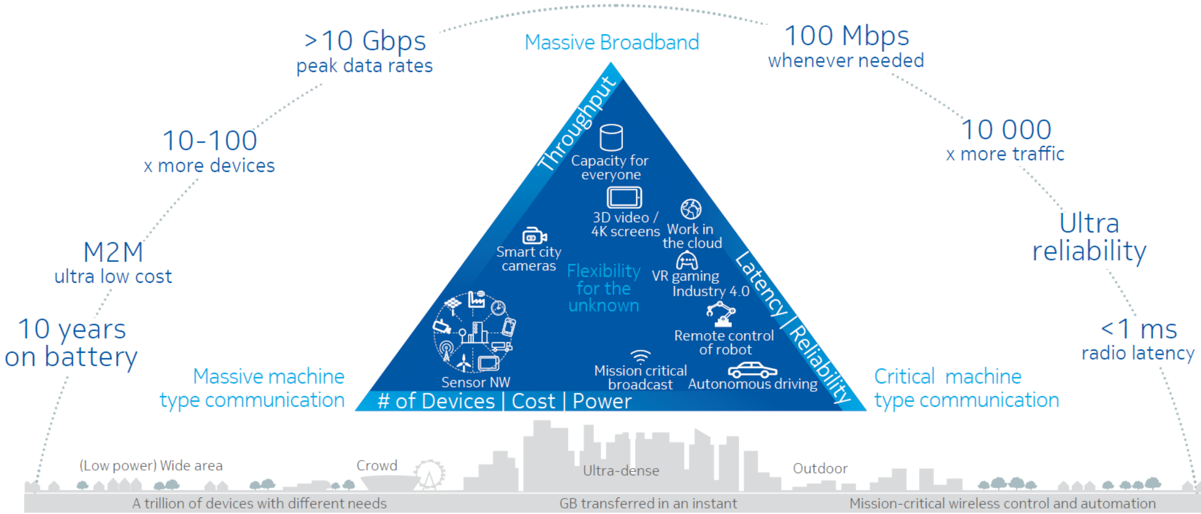


Figure 6 5G use cases and performance targets (source: Nokia)

The urgency for 5G has accelerated the standardisation work, with the 3GPP Release 15 **Non-standalone 5G New Radio (NR) standards** (utilising LTE radio and core networks as anchors) completed in the end 2017, and the **Standalone 5G NR standards** by mid-2018.[5] The earliest commercial 5G deployments are already expected by year 2019, mostly driven by needs for **enhanced mobile broadband (eMBB)** in dense urban areas. It is projected that by 2023, 5G will constitute 11% of the global mobile subscriptions with fastest adoption expected in North America, North East Asia and Western Europe regions (see Figure 7) [Ericsson2017].

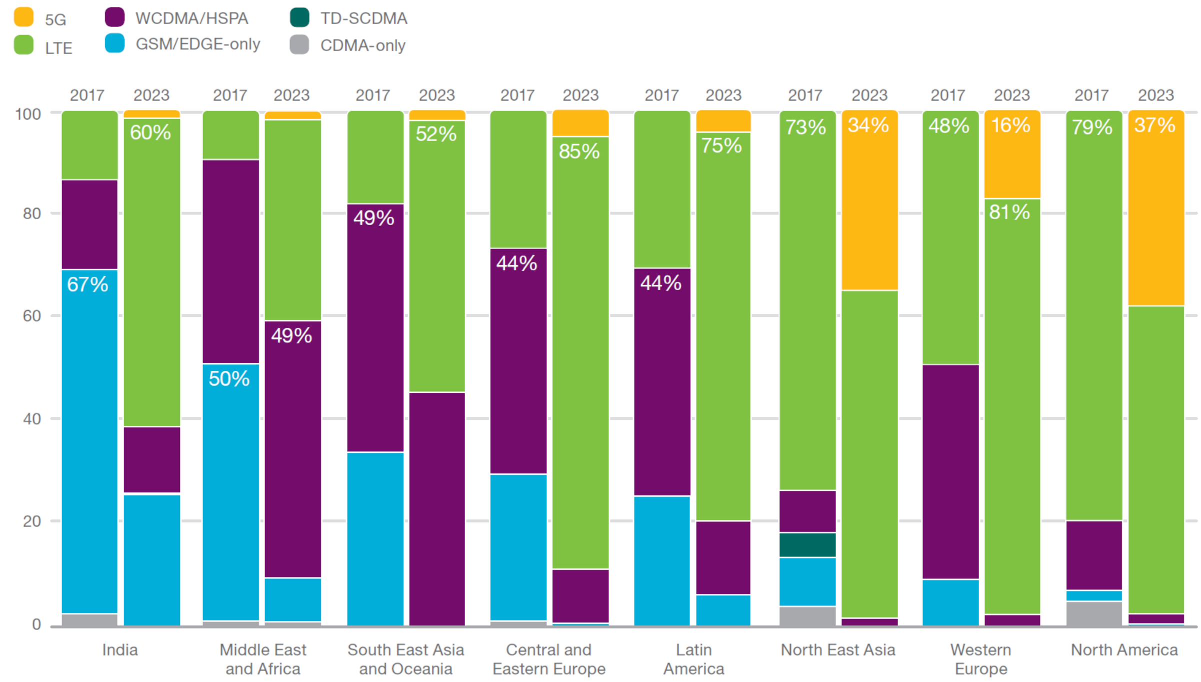


Figure 7 Mobile subscriptions by region and technology (percent) [Ericsson2017]

The deployment of small cells has been a critical part of the LTE network upgrades and expansion. To identify the inflection point, whereby, small cells become necessary to supplement macrocellular

[5] 5G-NR workplan for eMBB http://www.3gpp.org/news-events/3gpp-news/1836-5g_nr_workplan

networks, some experts have used the metric[6] traffic volume density per allocated unit of bandwidth (Gbps/km^2/Hz) [SCF2017i]. A pattern was noted in Japan, South Korea and other regions, whereby, operators would start to actively deploy small cells when the metric crosses the 0.02 Gbps/km^2/Hz threshold. This process of adding new cell sites (typically small cell sites), also referred to as **network densification,** is quantified by the site density (site/km^2) or inter site distance (ISD). Network densification is ongoing in legacy 4G/LTE networks with site densities of 10-30 sites/km^2 becoming increasingly commonplace [Nokia2016]. This preference for small cells is because they make it possible to:

- **Improve network coverage**: small cells can ensure connections indoor, outdoor in rural areas, on aircrafts, ships and trains (Over 80% of mobile usage occurs inside buildings).

- **Enhance spectrum efficiency,** exploiting existing spectrum in a more efficient way, allowing spectrum license holders to derive more value from their existing spectrum assets.

- **Improve network capacity:** small cells can increase cellular capacity in a given area more efficiently than placing more macrocells. A better signal-to-interference-plus-noise ratio (SINR) and smaller coverage footprint (less sharing of cell resources) means devices connected via small cells achieve higher throughput compared to macrocells. Moreover, small cells provide 'offloading gains' by allowing handover of users from overloaded macrocells to usually lightly loaded small cells, thus allowing more resources to be available to the remaining macro users.

- **Visual unobtrusiveness**, the form factor of small cells is suited for widespread deployment without creating unwanted visual impacts on urban structures including monuments and iconic buildings.

- **Lessen impact on health, increase safety**, since they transmit with very low powers, they are unlikely to impact human health and induce less interferences to sensitive equipment, for instance, in hospitals.

- **Lower energy power requirements**, the reduced powering requirements also lessens the carbon footprint attributed to small cells.

The need for small cells will be even more critical in 5G networks due to the introduction of higher spectrum bands, which necessitate denser network deployments to support larger traffic volumes per unit area [GSMA2017]. A network densification scenario envisioned for 5G is the deployment of **ultra-dense networks (UDNs)** with site deployment densities in excess of 90 sites/km^2 (or 112m ISD) [Nokia2017]. Table 1 below exemplifies the scaling site and traffic volume density from today's dense small cell deployments towards future UDNs. Another term that has found use in industry to describe intense network densification is **hyperdense networks**, which applies for site densities of 150 sites/km^2 (and could be as high as 1000 sites/km^2 for future 5G networks) [SCF2017i].

[6] Also known as GkM

Table 2 Site and traffic density evolution towards UDNs [Nokia2016]

	Traditional networks (2014)	Denser networks (2015-2017)	Very dense networks (2017-2020)	Ultra dense networks (beyond 2020)
Site / km2	7 sites	21 sites	26 sites	93 sites
ISD	395m	237m	209m	112m
Traffic volume density	~1 Gb/s/km²	~5 Gb/s/km²	~10 Gb/s/km²	~40 Gb/s/km²
Active users	250	625	1000	~2500

2.1.3 Deployment scenarios

The typical small cell deployment scenarios are outdoor deployments urban areas, outdoor deployment in rural and mostly indoor deployments enterprise spaces (see Figure 8).

In all scenarios the small cell deployments may be used to enhance coverage, in places where existing macrocells have coverage gaps (holes or blackspots), or macro coverage does not exist all. Furthermore, the small cells may provide capacity enhancements (by offloading traffic from macrocells) in densely occupied locations, which generate large traffic volume densities.

In addition to providing enhanced connectivity, small cells provide improved user experience through presence- and location-based enabled by the limited footprint of small cells [SCF2013b], especially in indoor locations where satellite-positioning methods are not available.

Moreover, recent developments towards 5G on **mobile edge computing (MEC)** or fog computing are leveraging **small cells as computing platforms** [Atreyam2016]. This enables distribution of cloud services to the edge of the network (closer to the user), thus reaching the user with maximum efficiency and reduced latency.

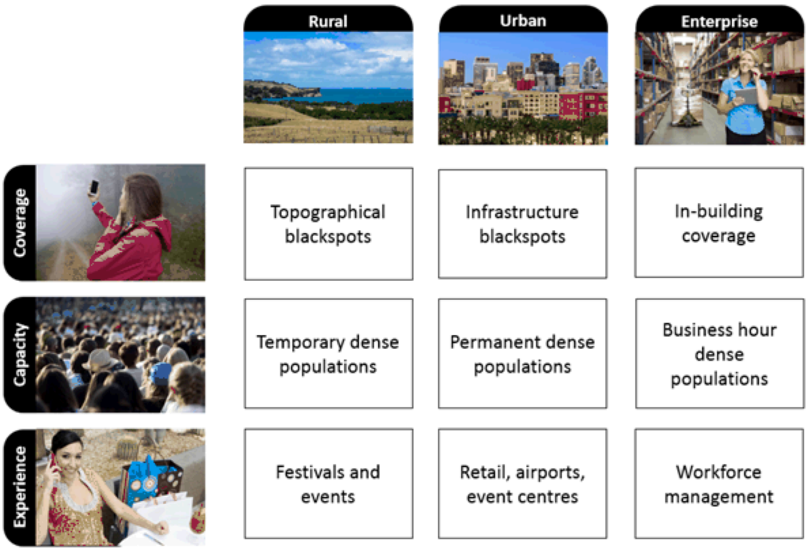


Figure 8 Deployment scenarios [Collier2017]

2.1.3.1 Enterprise scenarios

The enterprise deployment scenarios are generally indoor, premises-based deployments, which include, medium/large enterprise office buildings, shopping malls, hospitals, hotels, apartment blocks, government buildings, factories, underground facilities, campuses, as well as, partially open facilities, such as, stadiums [SCF2013].

To that end, enterprise scenarios may be closed access or private enterprise deployments (e.g. as part of the enterprise IT infrastructure in office buildings), or open access or public enterprise deployments (e.g. targeting customers in shopping malls). In both of these scenarios, indoor small cell deployments provide improved in-building coverage compared to outdoor base station deployments whose RF signals are attenuated when propagating from outdoor through building walls and windows. The indoor small cells are also better positioned to provide the capacity needed in usually crowded enterprise areas.

The new services enabled by small cells also provides enticing value propositions for enterprise owners who look to enhance the productivity of their employees or the experience of their visiting customers with edge cloud and context-driven services (see example of Figure 9).

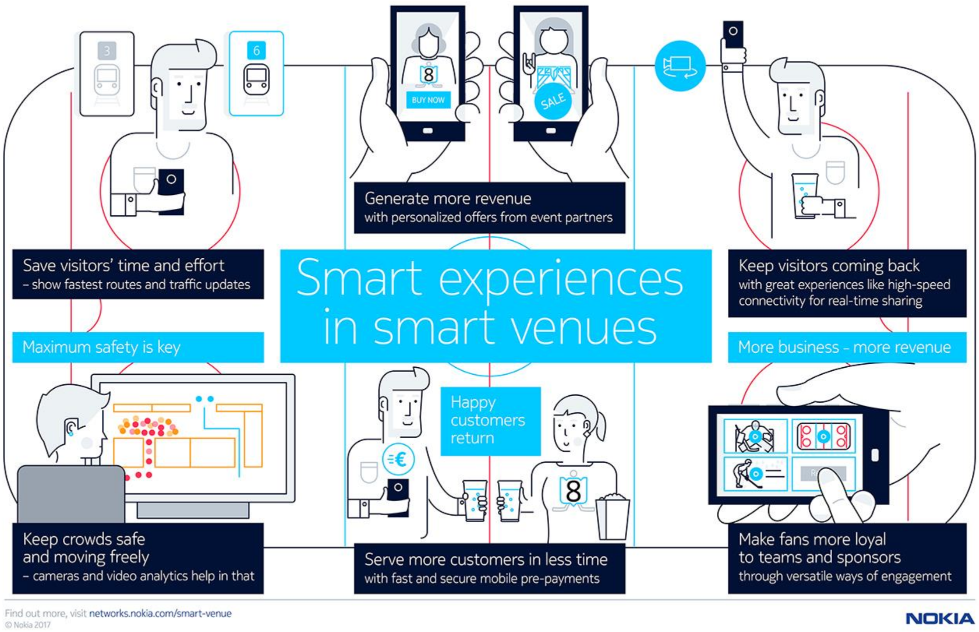


Figure 9 Smart venues services enabled by enterprise small cells and mobile edge computing (source: Nokia)[7]

2.1.3.2 Urban scenarios

The urban deployment scenario is driven by the operator need to provide spot coverage in places where there are outdoor coverage holes or blackspots (e.g. due to building shadowing) in existing macro coverage areas (see example of Figure 10). The urban environment also includes many permanently (or routinely) densely populated areas with large traffic density volumes, such as, street cafes, market squares and bus stops. These traffics hotspots would benefit significantly from the new capacity and additional services enabled by deployment of small cells in the outdoor urban area (providing similar experiences to those shown in Figure 9). Whereas macro base station deployments use radio towers or at rooftops of tall buildings, urban small cell deployments occur closer to the user at street-level using the side of the buildings, lampposts, advertisement boards and other so-called **street furniture**.

[7] https://networks.nokia.com/smart-venue

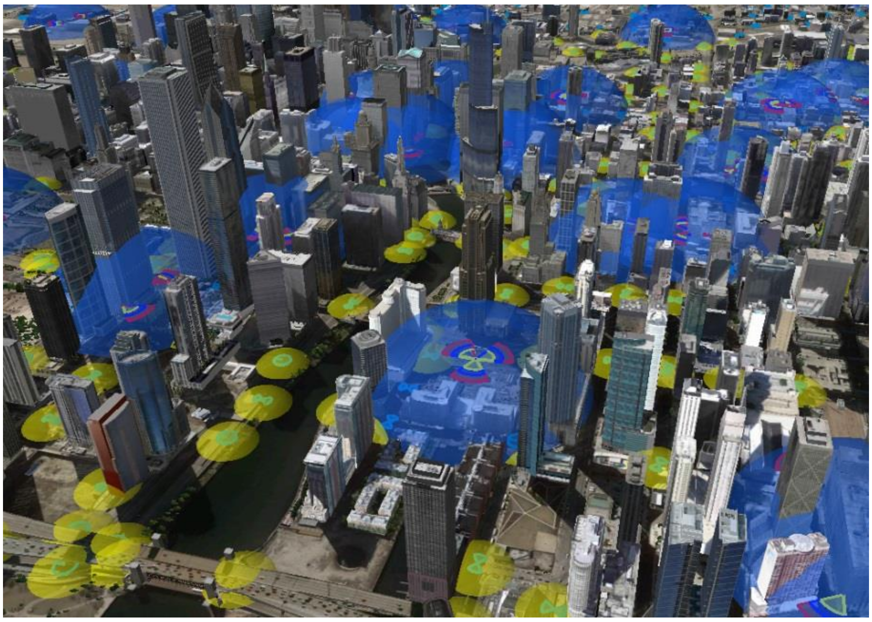


Figure 10 Example depiction of small cell coverage areas (yellow) and macro coverage (blue) in a network planning tool (Source: Forsk)

2.1.3.3 Rural scenarios

The rural deployment scenarios are typically motivated by the need to serve localized hotspots in remote areas, such as, small villages, mines and offshore oilrigs, which would otherwise be served from a distant macrocell tower, or which might not otherwise be economical to serve at all with macrocellular deployments. Rather than using a repeater, a small cell adds capacity and frees up the more expensive resource from the serving macrocell. Rural small cells designed to provide extended coverage range (compared to urban small cells), typically 1-2 km, which could be achieved through a combination of elevated antennas and higher RF transmit power.

The cost of a rural small cell operated using renewable energy sources (e.g. solar) and satellite backhaul, can be 80% less than macro base station site,[8] with low operating costs achieved by avoiding expensive site visits, including those to refill diesel fuel (a significant cost in remote areas). However, as rural scenarios are not a target of dense small cell deployments, their discussion in in the context of this study is limited.

2.1.3.4 Other scenarios

Beyond the conventional deployment scenarios described above, there is already increased attention on **mobile or nomadic small cell** deployments on cars, buses and so on. To that end, 3GPP is already considering this vehicular small cell connectivity or tethering to be one of the potential use cases of 5G vehicle-to-everything (V2X) [3GPP2017b]. In this scenario, the vehicle acts as a mobile small cell that provides network access to both vehicle occupants and pedestrians (see Figure 11). The vehicle provides several advantages (availability of power, higher number of antennas, size etc.) that make it a feasible site for small cells. Therefore, this scenario provides an opportunity for mobile network operators to provide network densification in urban areas (with high levels of slow-moving road traffic) without the usual high upfront costs of conventional fixed small cells.

Yet another deployment scenario that is receiving attention in research are drone small cells which are aerial wireless base stations that can be mounted on flying devices such as unmanned aerial vehicles (UAVs) [Mozafarri2017]. These drone small cells enable interesting opportunities to provide

[8] https://www.thinksmallcell.com/Small-Cells/Rural/

services to ground users in a variety of scenarios (e.g. disaster zones, unexpected hotspots etc.), but technical challenges, such as, backhauling and power remain an area of further research.

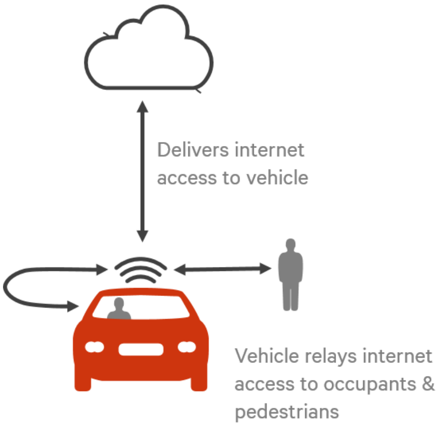


Figure 11 Example utilisation of a vehicle as mobile small cell [3GPP2017b]

2.2 Trends and projections

Mobile network operators in Europe and other regions have seen their LTE capacity running out in some locations and are forced to go beyond LTE extensions (e.g. carrier aggregation). This is compelling the operators to utilize small cells to alleviate capacity issues. It is expected that operators suffering from lack of spectrum will be the first to deploy small cells, primarily in dense urban areas.

In these cases, the primary issues will relate to the physical deployment of equipment, as well as, backhaul and interference management. For example, compared with macro cells, the services and site solution costs related to small cells will be higher as a proportion of overall cell site costs. The entry of third-party site facility providers that have access to assets like street furniture or street lighting will positively affect the deployment pace of small cells.

Moreover, the commercial deployment of 5G networks will further drive the need for densification, so as to, effectively translate the value of 5G upgrades to the subscribers. A snapshot of recent analyst reports predicts the next five years or so to be characterised by dense small cell across all global regions. The rest of Section 2.2 uses data obtained from Rethink Technology Research operator's survey (4th quarter 2017)[9] providing insights on trends and projections for small cell deployments up to year 2025.

Table 3 Selected projections on growth in small cell deployments from various sources[10]

Small cell projections	Source, Year
Number of LTE small cell sites in EMEA region will more than double between 2017 and 2019 reaching 260,000 sites	IDC [Hallilovic2016], 2016
Number of new small cells deployments will have CAGR of 14% between 2015 and 2025, reaching 11.4million in 2025, at which point the total small cell installed base will reach 70.2million.	Rethink Technology Research [SCF2017c], 2017
The growth for non-residential small cells will reach over 30% CAGR from 2016-2022	Mobile Experts, 2017[11]
Global small cell market to grow at a CAGR of close to 19% during	Technavio[12] 2017

[9] Detailed results from the Rethink Technology Research operator's survey Q42017 are provided in [SCF2017c]
[10] Note: CAGR = Compound Annual Growth; EMEA = Europe, Middle East and Africa
[11]https://www.prnewswire.com/news-releases/small-cell-market-will-rise-relentlessly-through-2017-300434914.html
[12]http://www.technavio.com/report/global-machine-machine-m2m-and-connected-devices-global-small-cell-market-2017-2021?utm_source=T3&utm_campaign=Media&utm_medium=BW

Small cell projections	Source, Year
the forecast period 2017-2021.	

2.2.1 Trends and projections in terms of density of deployments

The **new small cell deployments will be increasingly dense** as operators target urban and enterprise scenarios. Over 54% of the new deployments in 2017 a characterised as dense or hyperdense deployments (see Figure 12). The share of new dense or hyperdense deployments will increase to 78% as 5G is introduced with operation in the higher bands targeting hotspots and indoor areas.

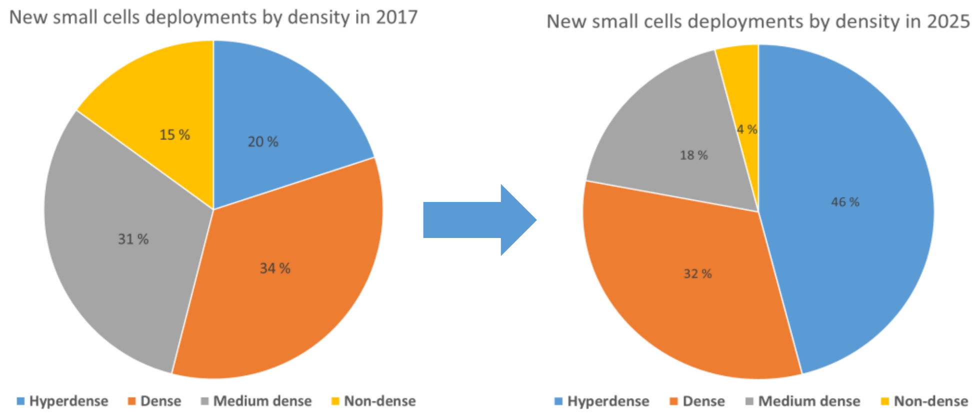


Figure 12 Share of new small cells deployments by density (Source: Rethink Technology Research [SCF2017c]

2.2.2 Trends and projections for different deployment scenarios

The small cell deployments have long been dominated by residential small cells or femtocells. These deployments were mostly driven by operator campaigns and promotions looking to collaborate with subscribers to improve signal quality in their homes. The SCF noted that number of installed 3G residential small cells first outnumbered 3G macro base stations in year 2011 [SCF2014]. The pace for deployment of residential small cells is projected to remain flat until 2025, whereas, **faster growth will be seen for enterprise and urban deployments** (see Figure 13) [SCF2017c], as operators address coverage holes and traffic hotspots in their LTE networks and ramp up the 5G rollout in urban areas.

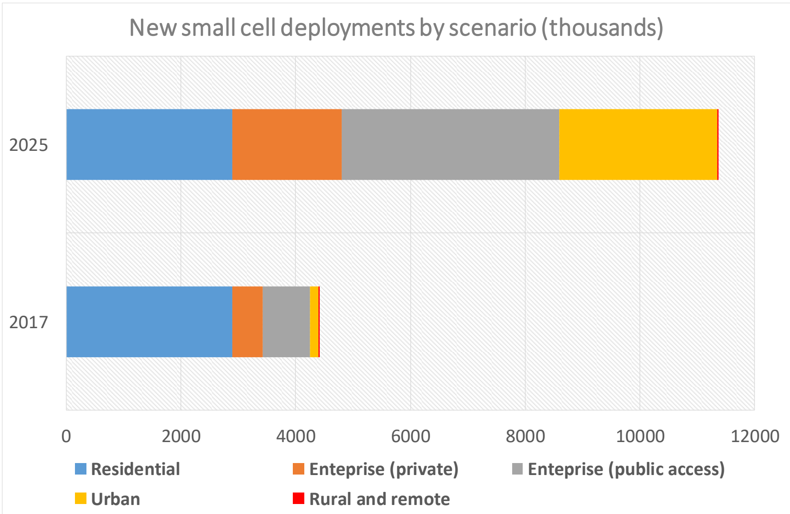


Figure 13 New small cells deployments by scenario (thousands) (Source: Rethink Technology

Research [SCF2017c]

2.2.3 Trends and projections for different global regions

Further interesting insights are noted from the small cell deployment projections across different global regions. It is observed that the adoption of small cells in Europe has so far lagged behind other regions, in particular North America and Asia-Pacific regions. This trend is noted for both enterprise deployments and urban deployment scenarios and is expected to continue well into the next decade (see Figure 14 and Figure 15). Major urban centres in Asia-Pacific began deploying small cells from 2014–2015 onwards, and today, some of the leading deployments can be found in Japan, South Korea, China, Hong Kong, and, more recently, India.

A number of factors contribute to the leadership in dense small cell deployments in this Asia-Pacific region and also influence the regulatory environment for small cell deployments in the region. This includes rapid economic growth driving the demand for broadband connectivity. This includes countries, such as, India, whereby, mobile networks are providing the first opportunity for broadband connectivity for majority of the population. The demography of the cities in this region also provide a more urgent need for dense small cell deployments, it is noted that currently 16 out of the top twenty most densely populated cities are in this region.[13]

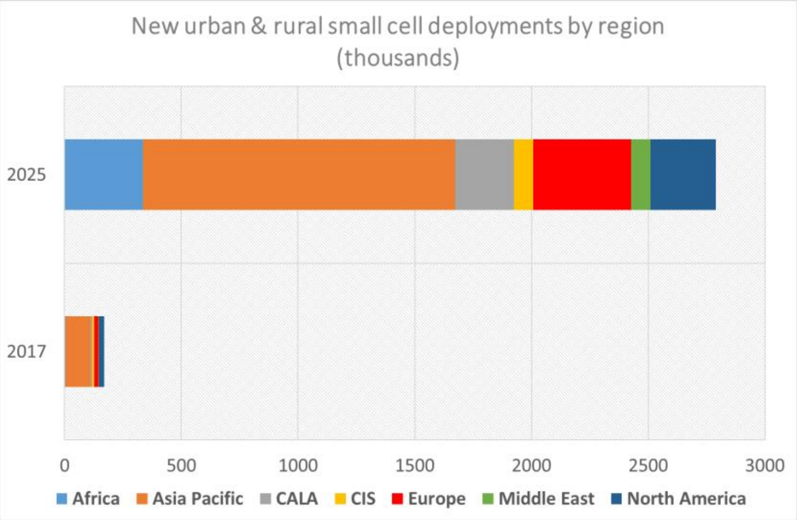


Figure 14 New urban and rural small cells deployments by region (thousands) (Source: Rethink Technology Research [SCF2017c]

[13] http://www.citymayors.com/statistics/largest-cities-density-125.html

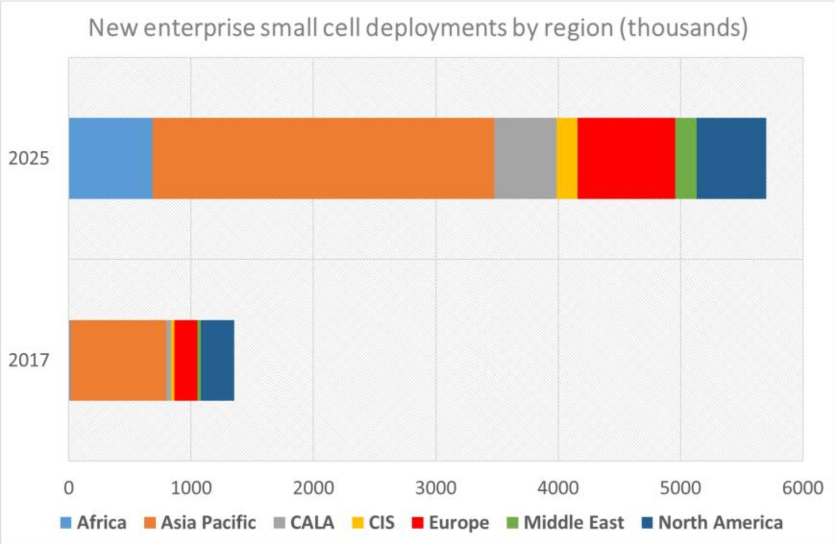


Figure 15 New enterprise small cells deployments by region (thousands) (Source: Rethink Technology Research [SCF2017c]

2.3 Deployment considerations

2.3.1 Spectrum

Legacy 4G networks utilised licensed spectrums bands typically in the sub-3 GHz range which provide wide area coverage. However, availability of spectrum in these bands is limited due to a multitude of other wireless systems that operate in the same range. This lack of sufficient spectrum also limited network densification due to need to reuse or share spectrum between the macrocellular and small cell layers. Recently, there has been the emergence of the possibility for LTE systems to coexist with Wi-Fi systems and utilise the 5 GHz unlicensed spectrum bands, which provides more spectrum resources for use by LTE small cells through use of technologies, such as, LTE-LAA (LTE-Licensed Assisted Access). LTE-LAA is part of the LTE-Advanced Pro (3GPP Release 13/14) enhancements and allows LTE small cells to aggregate available (locally unused) spectrum from the unlicensed 5 GHz band whilst always maintaining at least one licensed-band anchor connection for control-plane signalling traffic.

Future 5G NR systems will require even larger amounts of spectrum to support the small cell densification needed to meet performance targets for enhanced mobile broadband (eMBB) services. To that end, several newly allocated or targeted spectrum bands are already envisioned for 5G NR (see Figure 16). New 5G spectrum allocations in the mid-bands between 3 and 7 GHz is already targeted for early 5G NR deployments in different regions. For instance, in different EU Member States there have been public consultations and other actions by NRAs in the process of allocating 5G spectrum blocks within the 3.4 – 3.8 GHz frequency range (3.6 GHz band) [Qualcomm2017]. The contiguous bandwidth available in the 3.6 GHz band is relatively larger than the bandwidth that is available in the LTE bands, even with the use of carrier aggregation.

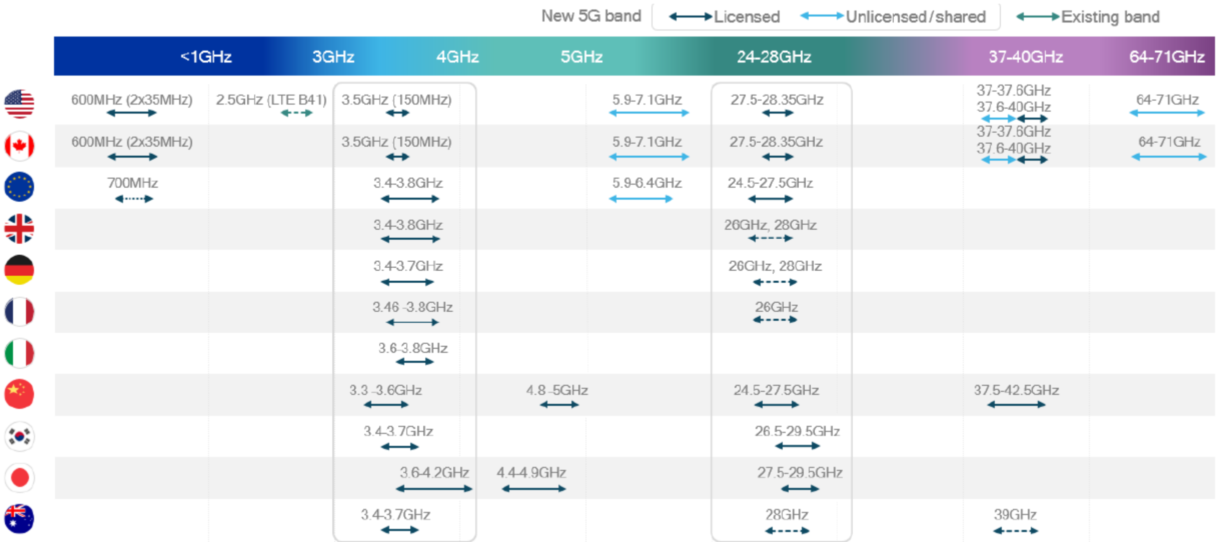


Figure 16 Allocated and targeted spectrum bands for 5G in different regions [Qualcomm2017]

However, future high band allocations in the millimetre wave (mmWave) bands (roughly above 24 GHz)[14] will provide even wider contiguous bandwidths (as high as 3 GHz) needed to deliver eMBB services. In Europe the 26 GHz band (24.25 – 27.5 GHz range) has been identified as another 5G pioneer band and there are efforts underway[15] in order to ensure harmonisation of the band in Europe in time for World Radiocommunications Conference (WRC-19)[16], so as to further promote this band for worldwide use. Additional work is also ongoing to evaluate mmWave bands higher than 26 GHz, such as, the 73 GHz band (also known as, E-band), which provides even higher bandwidths (10 GHz) shared with fixed or satellite links. The bandwidths available in these mmWave bands make them an ideal candidate for enabling 5G to fulfil targets of multigigabit-level data traffic and ultra-low latency. Moreover, millimetre wavelengths enable use of massive antenna arrays which provide beamforming (narrow beam transmissions only to target users), thus reducing interference and enhancing security.

On the other hand, the RF propagation characteristics at mmWave bands are challenging due to the higher path losses and stringent line-of-sight (LOS) requirements. These characteristics limit the possible cell range, particular in urban areas that create multiple obstructions in the signal path, such as, irregular building infrastructure, foliage and even random blockages from humans, vehicles and so on [mmMagic2015]. Another limitation at mmWave bands is the inability provide indoor coverage from outdoor sites, due to the high outdoor-to-indoor penetration losses as the signal propagates through building walls. These limitations inherently necessitate the massive deployment of small cells (in both indoor and outdoor environments) to fully realize the capacity enhancements 5G mmWave networks.

A recent example simulation campaign by Nokia revealed a number of interesting observations on the densification requirements at mid and high-bands [Nokia2017b]. The case studies were a simplified and realistic urban case studies, for Madrid and Tokyo, respectively (see Figure 17), with 5G small cells operating at 10 GHz and 73 GHz, and LTE-Advanced macro layer at 2 GHz for wide area coverage. The simulation study conclusions noted that outdoor mmWave small cells (75-100m inter-site distance) provided an up-to 10,000-fold capacity increases in outdoor urban areas, however, dedicated indoor mmWave small cells deployments would be required to satisfy capacity demand in

[14] The term centimetre wave (cmWave) is sometimes used to refer to the 6-30 GHz, whereas, mmWave band is for 30-100 GHz band. However, for this report, mmWave will be synonymous with the high bands above 6 GHz (up to 100 GHz).

[15] https://cept.org/ecc/topics/spectrum-for-wireless-broadband-5g

[16] World radiocommunication conferences (WRC) are held every three to four years, with aims that include revising the international treaty governing the use of the radio-frequency spectrum https://www.itu.int/en/ITU-R/conferences/wrc/2019/Pages/default.aspx

indoor areas. Furthermore, the use of LTE-Advanced macro layer remains useful to cell edge performance and reducing the required density of small cell deployments. Moreover, the mmWave deployments with 2 GHz bandwidth can provide the area capacity of several Tbps/km^2 that may be demanded by 5G systems towards 2030 [Nokia2017b].

Madrid case study   Tokyo case study

Figure 17 Madrid and Tokyo simulation case studies [Nokia2017b]

2.3.2 Backhaul and Fronthaul

Mobile networks are not only wireless access networks, but also include fixed links which connect base stations to a mobile core or public internet network. These fixed (wired or wireless) links that connect the cellular base stations to each other and the core network, are known as backhaul links, which may form the backhaul network. The **technology selection and design of the backhaul links is critical for the achievable performance of the overall service provided over the mobile network**. Any limitations on backhaul link capacity would create a bottleneck for possible served capacity of base station utilising the backhaul link. Similarly, the delays over the backhaul link could be a significant contribution to the end-to-end latency experienced by a service provided via a mobile network.

A number of small cell backhauling solutions are possible depending on the small cell deployment scenario [NGMN2012, Robson2012]. Indoor-deployed small cells (e.g. enterprise femtos) can be backhauled using existing in-building wireline infrastructure, such as, copper twisted-pair digital subscriber lines (DSL), fibre and coaxial cables (for cable television). Outdoor-deployed small cells in most cases do not have access to legacy cabling and the cost of Greenfield rollout of cables to each small cell would be prohibitive [Robson2012]. Therefore, wireless backhauling solutions are usually considered for outdoor small cells [NGMN2012, Nokia2013, Robson2012]. These include backhauling links based on traditional sub-6 GHz wireless links, microwave/millimetre wave fixed radio links (including links in the 6-50 GHz, 57-66 GHz and 71-95 GHz spectrum regions), free-space optics and satellite. The differentiating attributes for the different wireless backhaul solutions include:

- *Operating spectrum band*: Differs depending on spectrum licensing arrangements (licensed or unlicensed bands). Differences may also be in spectrum allocation between small cell backhaul and access links, whereby, utilized spectrum bands are either overlapping (inband) or orthogonal (outband) between the access and backhaul links.

- *Capacity*: Typical capacity (bits per second) available over the backhaul link. The available capacity for different wireless backhaul solutions depends on the amount available spectrum resources, co-channel interference and radio propagation characteristics for given operating spectrum band (utilised by the backhaul link).

- *Deployment topology*: Configuration between small cells and backhaul hub point. Common configurations are point-to-point (P2P), point-to-multipoint (P2MP), tree, and mesh topologies.

- *Line-of-sight (LOS) requirements*: This refers to the constraints on having a clear unobstructed signal path between the wireless transmitter and the receiver. The backhaul link LOS requirements may have strict LOS requirement, near LOS (nLOS) requirement (partially obstructed signal path) and non-LOS (NLOS) requirement (LOS constraints are fully relaxed).

These aforementioned attributes strongly influence the selection of wireless backhaul solution for a particular deployment scenario. Typically, small cell operators have to consider the trade-offs among factors, such as, required performance (depending on the RAT of backhauled small cell), total cost of ownership and feasibility or ease of deployment [NGMN2012, Nokia2013, Robson2012].

Legacy 4G (and evolved 4G) networks utilise LTE, which has primarily designed to carry mobile broadband traffic. By contrast, 5G networks are developed to simultaneously handle heterogeneous services types with varying performance requirements, which subsequently influences required backhaul link performance. The 5G backhaul performance impact for different service categories includes:

- *Enhanced mobile broadband*: Support even higher data traffic services resulting in 1000x increase in mobile data volume per geographical area (compared to 4G), which dramatically increases demand for backhaul capacity;

- *Massive machine-type communications*: Increased need for network (including backhaul) scalability and flexibility to support up to a million devices per km^2 (in urban areas);

- *Ultra-reliable low-latency communications*: Critical machine-type connectivity for services that typically demand sub 1ms latency (5x improvement in end-to-end latency compared to 4G LTE) and high reliability (success probability of transmitting a given number of bytes within 1ms under a certain channel quality).

Apart from aforementioned 5G service traffic types, the envisioned 5G network will also provide a common core for a multitude of wireless technologies (legacy cellular, Wi-Fi, fixed wireless) and multitenancy for infrastructure sharing by different operators. These will put further demands on the 5G backhaul infrastructure.

Furthermore, the evolution towards 5G is creating a scenario where multiple RAN architectures may coexist in future networks and also impact the backhaul design (see Figure 18) [Nokia2017]. In legacy “distributed RAN” architectures, both the radio and baseband functions are co-located at the cell site and conventional backhaul links provide connectivity towards the core network. However, there is increased interest in centralised RAN architectures due to possible enhancements in capacity and coverage, improved self-organisation and coordination, improved security and cost reductions for dense deployments. Of these, the “centralized RAN” architectures have the radio functions located at distributed cell sites and are split from the baseband functions located in a centralised baseband unit (BBU). The connection between these cell sites (remote radio heads [RRH]) and the centralised BBU is provided by **fronthaul links**, whereas, backhaul links connect the centralized BBU towards the core network.

The increased cloudification/virtualization of RAN functions enables “Cloud RAN” architectures, whereby, part of the baseband functions are partially hosted in a centralised cloud location and distributed cell sites connected to the cloud by fronthaul links. The actual split of baseband functions between these locations can be performed at different levels, based on different requirements for fronthaul link capacity and latency. The more real time functions are moved to centralised locations the stringent latency requirements and capacity needs for the fronthaul links. A more detailed investigation of these trade-offs and study of the required backhaul/fronthaul technologies for 5G small cells has been carried out by the 5G-PPP 5G-Xhaul project [5GXHaul2015].

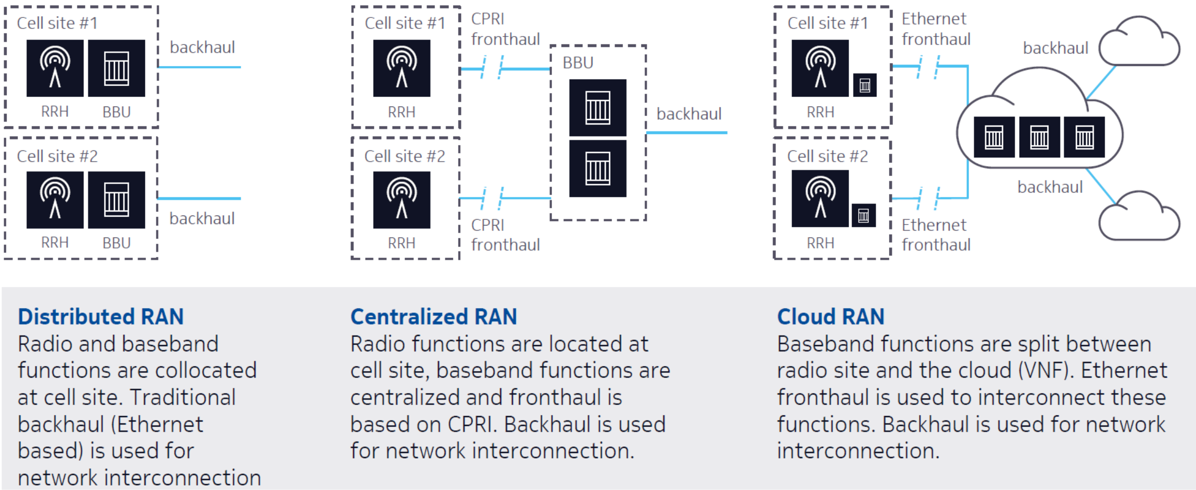


Figure 18 Different RAN architectures for future networks [Nokia2017]

Overall, the backhaul/fronthaul requirements for 5G-ready dense small cell capacity are summarised in Table 4.

Table 4 Requirements on backhaul/fronthaul imposed by densification in 5G networks

Attribute	**Backhaul/fronthaul requirements imposed by 5G dense small cell networks**
Architecture	Migration towards more centralised RAN architectures that put stringent performance targets on both fronthaul and backhaul segments
Capacity	High capacity fronthaul/backhaul connectivity solutions (e.g. fiber links with 400G interfaces) to support high capacity small cells operating with wider bandwidths, more antennas etc. Approaches for statistical multiplexing and joint optimisation of access and backhaul/fronthaul could be used to manage scalability of capacity requirements.
Coverage/Reach	Connectivity links able to reach large number of small cells deployed outdoors at street-level (below rooftop) and in a multitude of indoor locations. For wireless backhaul/fronthaul approaches, such as, mesh networks and self-backhauling could be considered to extend reach.
Physical design	Solutions that allow for flexible, easy and rapid installation of backhaul/fronthaul links for a large number of outdoor and indoor small cells
Programmability	Migration towards network softwarisation and virtualisation (through NFV and SDN) is changing how functions/services are created, managed, optimized and terminated across the network. This implies that backhaul/fronthaul segments should be more flexible and responsive to any rapid change in requirements for different services.
Total cost of ownership	Increasing density of small deployments requires measures (infrastructure sharing, reduced footprint etc.) to keep the backhaul/fronthaul TCO sustainable for operators

2.3.3 Powering

Small cells products consume much lower power compared to macro base stations due to a reduced coverage area (e.g. less transmit powers) and the less requirement for site support infrastructure (e.g. cooling systems). Table 5 exemplifies the differences in the transmit powers for various base station classes specified by 3GPP TS 36.104, providing comparative figures for wide area (macro) base stations and other various small cell base station types. In this case, the rated total output power of the base station refers to the mean power for a base station operating in single carrier, multi-carrier, or carrier aggregation configurations that the manufacturer has declared to be available at the antenna connector during the transmitter ON period.

Table 5 3GPP defined rated output powers for different BS classes [3GPP2017]

3GPP BS Class	3GPP Rated Output Power	Comment/Examples
Wide Area BS	No upper limit	This class essentially refers to macro BSs. The typical output powers are 43-48 dBm (or 20-69 W) at the antenna connector.
Medium Range BS	≤ + 38 dBm or 6.3 W	Urban microcells or metrocells
Local Area BS	≤ + 24 dBm or 250 mW	Picocells deployed in outdoor hotspots or indoor public spaces (e.g. concert venues)
Home BS	≤ + 20 dBm or 100 mW (for one transmit antenna port) ≤ + 17 dBm or 50 mW (for two transmit antenna ports) ≤ + 14 dBm or 25 mW (for four transmit antenna ports) < + 11 dBm or 12.5 mW (for eight transmit antenna ports)	Enterprise small cell deployed per office Residential small cells deployed per household or room

The increased network densification in 5G (more sites that require powering) implies an overall increase in network-wide energy or power consumption. The 5G small cells will consume power in a number of ways, including:

- *For transmission purposes*: to produce signals both in the radio access and in the backhaul or fronthaul segments.
- *For computation purposes*: to enable operation of the baseband unit (e.g. digital signal process) and edge cloud processing in the case of MEC implementations.

These growing energy requirements put a constraint possible densification due to unsustainable site powering costs and increase in the carbon footprint with site density. Therefore, **green or power-efficient small cell product designs are critical to overcome this 'powering barrier' to densification** (e.g. see [Ge2017], and references quoted therein). The addition of 5G NR to existing LTE sites (5G NR non-standalone architecture) will initially result in higher site power consumption to the wider operating bandwidths and larger number of antennas (more radio chains). However, subsequent 5G NR base station product releases will utilise 'ultra-lean design' approaches, such as, longer sleep periods for base stations [Frenger2017], to achieve radical reductions in site power consumption in both non-standalone and standalone site configurations (see Figure 19).

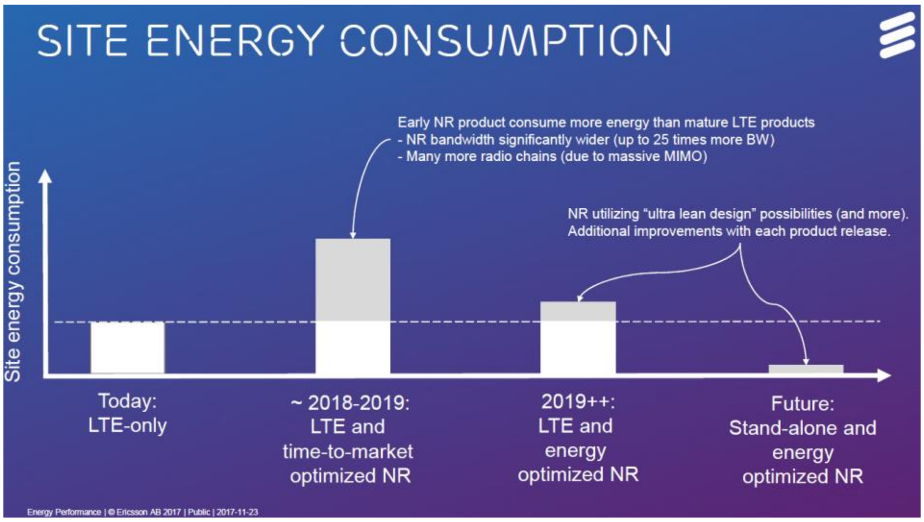


Figure 19 Improvements in site power or energy consumption in future 5G NR products [Frenger2017]

The power-efficient 5G NR base station designs may also increase the possibility of running the small cells off-grid (using renewable energy sources [Mao2015] or Power-over-Ethernet[17] [Skyworks2017]). This enables significant reductions in the installation costs for providing power grid connectivity to every small cell site in dense network deployments. Furthermore, the lowered transmit powers of the small cells reduces further the human exposure to RF radiations (to be discussed further in Section 2.3.5).

2.3.4 Sharing and different commercial models

The sharing of network infrastructure is a well-established practice in the mobile industry [Neumann2017]. This mobile network infrastructure sharing take a number of forms, including contractual agreements or joint ventures between independent MNOs. Also increasingly common approach is the outsourcing of the provisioning of certain site infrastructure and/or infrastructure services (e.g. site maintenance) to third party providers. The emergence of radio tower companies[18] is exemplifies the typical form outsourcing in macrocellular networks.

In general, there have been two ways of practically implementing sharing in mobile networks, namely: **passive sharing** and **active sharing** (see Figure 20)[19]. The main distinctions are as follows:

- *Passive sharing*: Sharing approach whereby multiple MNOs share physical space and site infrastructure (masts, utility poles, advertisement panels, fixed-plant for backhauling etc.), but the active network elements remain separate. Passive sharing is of interest to MNOs because the sharing is mediated by a neutral third party (e.g. telecom tower companies), which serve multiple MNOs in each site, even as their individual networks remain competitively independent of each other. In some countries passive sharing is even mandated by law or regulation [Neumann2017].
- *Active sharing*: Sharing approach whereby multiple MNOs share some or all active elements of network (e.g. base station hardware, backhaul interfaces, or even elements of the core network) and in some cases, it may include the sharing of spectrum. The level cooperation between MNOs is higher in active and is driven by need for cost saving or collaborations effectively fulfil coverage obligations. The current active network-sharing approaches include:

[17] Power-over-Ethernet (PoE) enables use of Ethernet cabling both for backhauling and adding DC power for powering the small cell [Skyworks2017].
[18] According to forecasts by Research and Markets, the global telecom tower market is a is expected to grow at a CAGR of 25.2% in the forecast period 2016 - 2021 https://www.researchandmarkets.com/research/jd2jhx/global_telecom
[19] Figure 20 is generalised by depicting elements for 2G, 3G and 4G networks

- Multiple Operator RAN (MORAN), whereby, the base station baseband and RF equipment are shared, but the MNO carriers and radio resource management remain separate.
- Multiple Operator Core Network (MOCN), whereby, the RAN is shared.
- Gateway Core Network (GWCN), whereby, both RAN and some core network functions are shared.

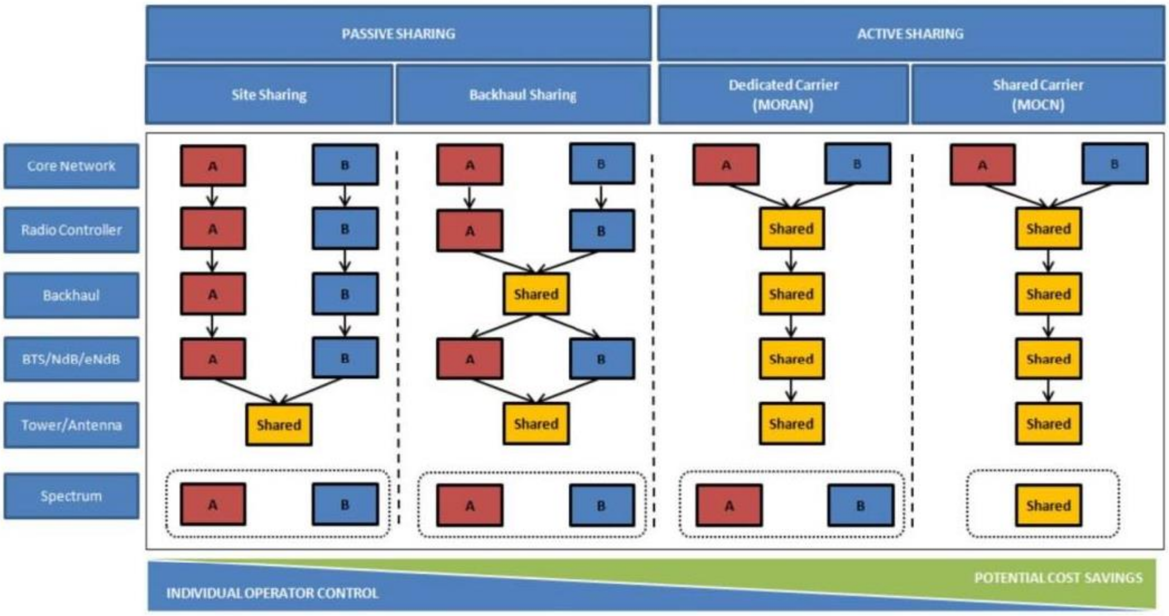


Figure 20 Different forms of mobile network sharing [Neumann2017]

Infrastructure sharing is even more critical for small cell networks due to the required density of deployment and the wider diversity of deployment scenarios [SCF2016b]. This has seen the emergence of **neutral host** providers as a key stakeholder in small cell deployments and they are projected to own majority of the deployed small cells by 2020 (see Figure 21).

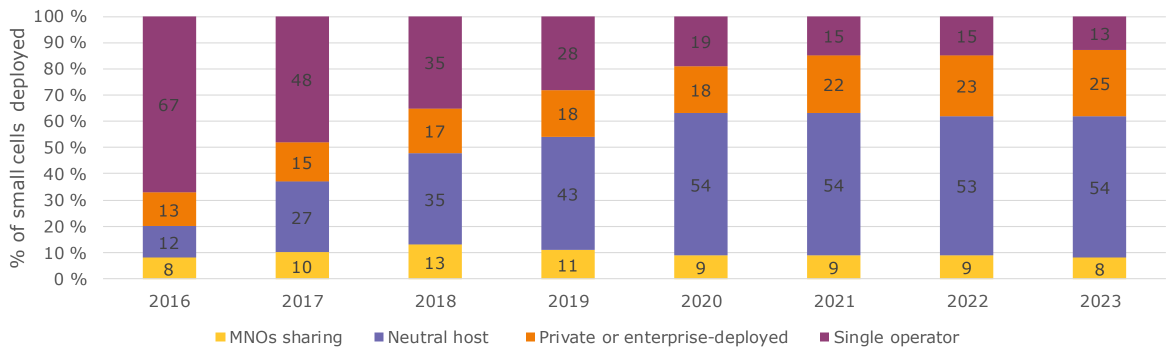


Figure 21 Percentage of small cells by ownership model (Source: SCF survey Q317)

Neutral hosts are companies that leverage their existing infrastructure (e.g. buildings, utility poles, advertisement panels etc.) to deploy and provide small cells for exclusive or shared use by other MNOs using active sharing solutions. Neutral hosts are different from MNOs as they themselves do not provide communications services that compete with the MNOs. The term **small cell infracos** is sometimes used to refer to neutral hosts [Casad2017]. As small cell physical designs are typically integrated in a single package, there are few passive elements (e.g. cooling systems, separate base station antennas, etc.) making passive sharing less useful. Therefore, active sharing approaches are commonly utilised for multiple-operator and neutral host small cells

The neutral host service is a **Small-cells-as-a-Service (SCaaS)** model that significantly lowers of the entry barrier for some MNOs who intend to have dense small cell deployments in both indoor and outdoor areas [SCF2016b]. SCaaS model by neutral hosts may go beyond providing infrastructure to include functions or services, such as, service management and billing. The entrance of neutral hosts extends the possible business or commercial models (compared to MNO only models) depending on the collaboration between the neutral hosts and MNOs at different phases of the deployment process. Some of different commercials models that are possible are illustrated in Figure 22.

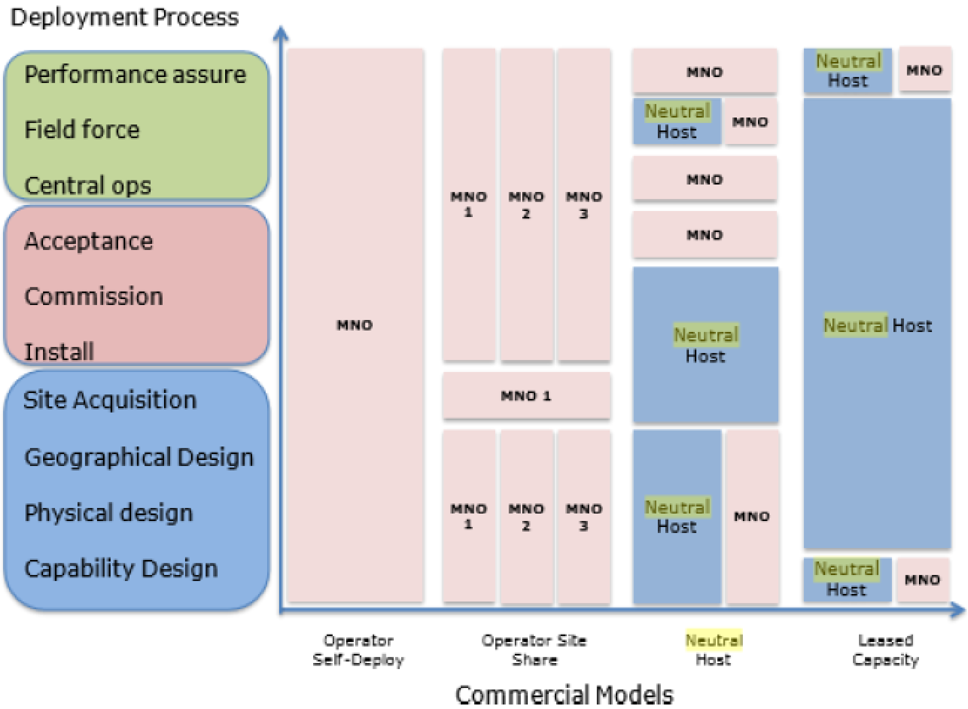


Figure 22 Commercial models for dedicated or shared small cells [SCF2016b]

The **sharing of small cells will be even more critical in 5G networks** due to increased level of network densification required to fulfil 5G performance targets. An emerging approach for small cell sharing in future networks is with use of **network slicing**, which is realised using technologies, such as, **Software-defined networking (SDN)** and **network functions virtualization (NFV)** [5GAmericas2016, Li2017]. The implementation of network slicing is conceived to be an end-to-end feature that includes the core network and the RAN [5GAmericas2016], whereby, each slice (e.g. allocated per MNO) can have its own network architecture, engineering mechanism and network provisioning (see example illustration of Figure 23).

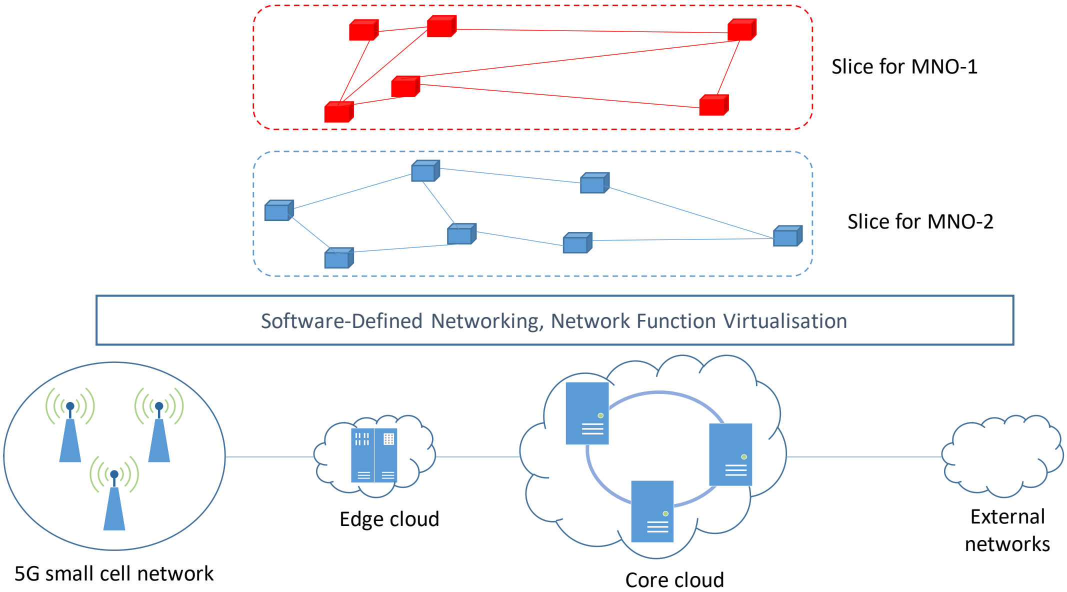


Figure 23 Example conceptualisation of network slicing for small cell sharing

Network slicing enables the virtualisation and dynamic allocation of most network and service functions (for connectivity, computing or storage), to support on-demand, elastic, pay-as-you-go cloud services paradigms suited to network sharing. These may include the previously mentioned SCaaS, spectrum-as-a-service, network-as-a-service and so on. Compared to legacy small cell sharing solutions, network slicing enables sharing in a way that is:

- *More scalable*: Small cells owners are able to accommodate many more tenants and new types of service providers (not just MNOs, but also 5G industry verticals and so on);
- *More affordable*: Tenants only pay small cell rental fees when they use the small cells;
- *More customisable*: Small cell owners able to meet the diverse requirements for different tenants based on QoS, geography, availability and Service Level Agreements.

The sharing possibilities of virtualised and cloudified small cells are numerous. This has prompted a number of industry and research stakeholders to explore small cell sharing use cases enabled by network slicing. For instance, the 5G-PPP Phase 2 project 5G ESSENCE[20] is exploring and demonstrating the use of slicing for small cell sharing in stadiums, emergency response and inflight entertainment scenarios. The SCF has also specified multivendor standardised interface (nFAPI) between the physical network functions (PNFs) and virtual network functions (VNFs) of a small cell network [SCF2016b]. This would enable decoupling of cluster of small cell hardware (PNFs) deployments from the controller of the small cells (VNF). In a typical envisioned sharing scenarios, the controller could belong to a neutral host, cloud-based service provider or be implemented as individual controllers of different tenants who would like to retain control of functions (e.g. for resource allocation).

2.3.5 Safe operation

The deployment and operation of radio frequency (RF) transmitters, such as, small cells, raises safety considerations due to human exposure to **electromagnetic fields (EMF)**. The human exposure to EMFs is actually a regular occurrence in daily life due to the ubiquitous presence of EMF sources

[20] H2020 5G ESSENCE (Embedded Network Services for 5G Experiences) http://www.5g-essence-h2020.eu/Home.aspx

across the electromagnetic spectrum (see Figure 24) and can be attributed to both natural sources (e.g. the sun), as well as, artificial EMF sources (televisions, wireless networks, etc.). The RF signals from wireless equipment (e.g. small cells), are referred to as non-ionizing, that is, they do not directly impart sufficient energy to break a molecule or alter chemical bonds [ITU-T2017]. This is in contrast to ionizing radiation (e.g. X-rays), which may cause tissue damage or even cancer due to the ability of the radiation to strip of electrons from atoms and molecules. In any case, over the last few decades there has been extensive research[21] to understand the potential health risks due of long-term human exposure to RF-EMF produced by mobile phones, base stations and other wireless devices and equipment.

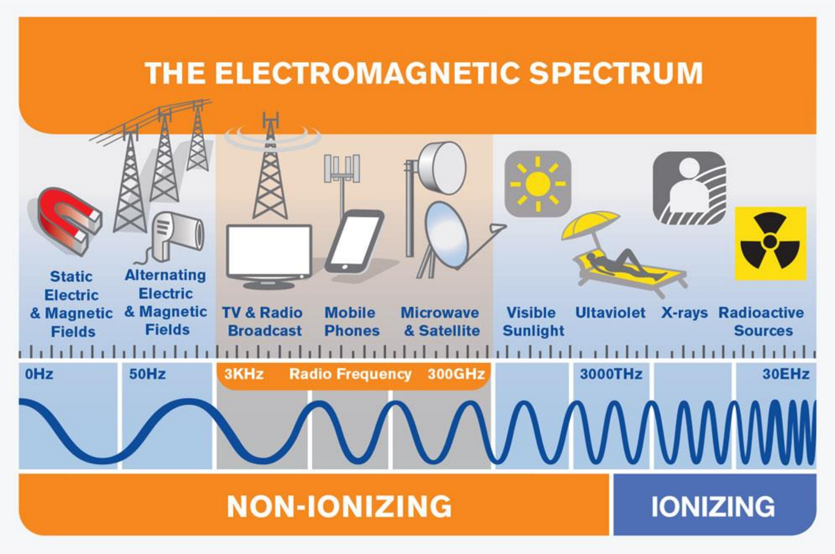


Figure 24 Typical sources of EMF at different parts of the electromagnetic spectrum (source: ITU-T)

The results of the aforementioned research studies have enabled development of international exposure guidelines for various systems, including wireless systems and devices. The international exposure guidelines usually developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which in 1998 originally proposed RF-EMF guidelines for frequencies up to 300 GHz [ICNIRP1988]. The ICNIRP guidelines are recognised by the World Health Organisation (WHO), which encourages the adoption of the guidelines by different countries and states the following[22]:

> *"Extensive research has been conducted into possible health effects of exposure to many parts of the frequency spectrum including mobile phones and base stations. All reviews conducted so far have indicated that exposures below the limits recommended in the ICNIRP (1998) EMF guidelines, covering the full frequency range from 0-300 GHz, do not produce any known adverse health effect. However, there are gaps in knowledge still needing to be filled before better health risk assessments can be made."*

The ICNIRP guidelines also forms the basis of the ITU recommendations related to RF-EMF exposure limits [ITU-T2016], as well as, the corresponding standards from the European Committee for Electrotechnical Standardization (CENELEC) [CENELEC2008]. The EC also issued a recommendation in 1999 to limit public exposure to electromagnetic fields (0Hz-300GHz) based on in

[21] GSMA maintains a list of reports (from 1978 to present) by national and international bodies, whose conclusions are informed by scientific research on potential health risks of wireless equipment and devices http://www.gsma.com/publicpolicy/mobile-and-health/science-overview/reports-and-statements-index
[22] http://www.who.int/peh-emf/research/en/

the ICNIRP guidelines [EC1999]. ITU notes that national EMF exposure limits based on the ICNIRP guidelines provide a global reference, an internationally harmonised approach and a global consistency of exposure protection. The ICNIRP RF-EMF guidelines provide threshold level above which the health effects due to exposure have been established due to thermal effects of RF-EMF (through absorption of RF-EMF energy and subsequent tissue heating). The guidelines then apply a reduction factor of 10 and 50 to establish a safe exposure level for workers (occupational exposure) and the general public, respectively, so as to account for any scientific uncertainties, environmental conditions and variations in the health of the population (see Figure 25). Following the 1998 ICNIRP guideline

.

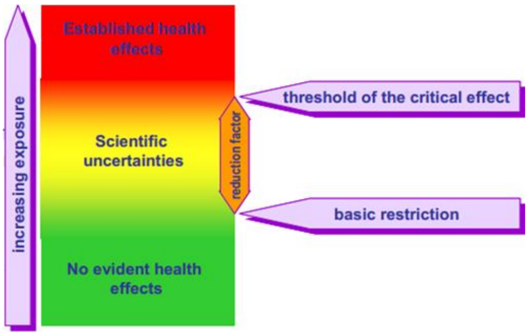


Figure 25 Usage of reduction for ICNIRP exposure limits (source: ICNIRP)

The ICNIRP RF-EMF exposure limits (basic restrictions) provide the fundamental limits on exposure to time-varying RF-EMF, whereas, “reference levels” are derived from the basic restrictions and the relationship between exposure to an incident field and the power absorbed by a human body. The ICNIRP are expressed in terms of **specific absorption rate** (SAR, Watt/kg) in the 10 MHz – 10 GHz frequency range and using the **incident power density** (W/m^2) for the 10 GHz – 300 GHz frequency range [ICNIRP1998]. Furthermore, the reference levels are expressed as electric field (V/m), magnetic field (A/m) and power density (W/m^2), to enable RF measurement equipment to be used to determine compliance with SAR limits (brief details of the ICNIRP limits is provided in the appendix of Section 9). Detailed guidelines of compliance assessments are specified in standards, including those of ITU [ITU-T2017], the Institute of Electrical and Electronics Engineers (IEEE) [IEEE2010], and the International Electrotechnical Commission (IEC) [IEC2017]. In some countries, national requirements are specified based on some of these international technical standards.

In wireless systems, the RF-EMF exposure levels decrease as a person moves away from an RF transmitter, such as, a small cell transmit antenna. The RF-EMF exposure level is evaluated by calculations based on the antenna characteristics or through measurements typically for complex sites with multiple transmit antennas with overlapping patterns or locations with many reflecting objects. To the end, the **compliance distance** is a conservative safety margin derived based on field strength, SAR or power density, and is essentially the distance from the antenna beyond which the evaluated RF-EMF exposure level (from the small cell) is below the RF-EMF exposure limit. Another method for expressing compliance bounds is through the evaluation of a three-dimensional (3D) **compliance boundary** or **exclusion zone** around an antenna, which provides a compliance distance in all directions (see example of Figure 26). The compliance boundary information for a particular base station product is normally determined for a number of selected typical configurations (operating frequency band, number of transmitters, system bandwidth, antenna, feeder, etc.) of the product, assuming free-space conditions, and at the maximum power for each configuration [IEC2017].

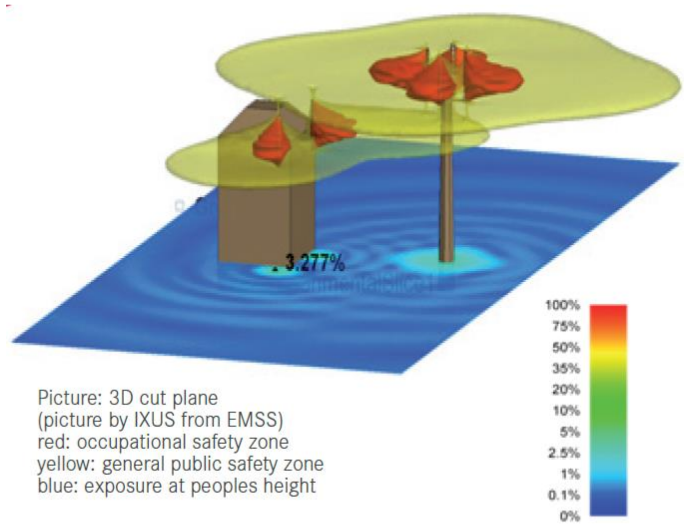


Figure 26 Example depiction of exclusion zones from an EMF exposure evaluation software for an area with multiple antennas (source: IXUS)

Small cells as a source of RF radiation may probably undergo assessment of EMF compliance at various phases (product certification/acceptance, installation or operation phase). However, the relatively lower transmit powers of small cells compared to conventional macro base stations (as noted in Section 2.3.3), usually forms the basis of arguments of exemption of small cells in some of these compliance assessment processes. The discussions on the compliance assessment of small cells and implications for network densification are revisited in Section 4.2.3.

The projection of the impact of the evolution to 5G on RF-EMF exposure levels remains to be an area of intense study [Lewicki2017]. The 5G NR enhancements will create need for denser deployments of emission sources (5G small cells) typically operating in higher bands and with wider bandwidths, as noted in Section 2.3.1. Moreover, the 5G small cells may be equipment with massive MIMO antenna arrays for further SINR performance enhancements. The gradual transition to 5G will mean that multi-RAT small cells (with 5G NR plus other preceding RATs e.g. LTE) will constitute the majority of the deployments even after 5G becomes available. For instance, the recent Ericsson Mobility Report (of November 2017) projects that LTE will still account for 60% of mobile subscriptions in 2023, compared to 5G subscriptions accounting 11% of the overall subscriptions (see Figure 27) [Ericsson2017].

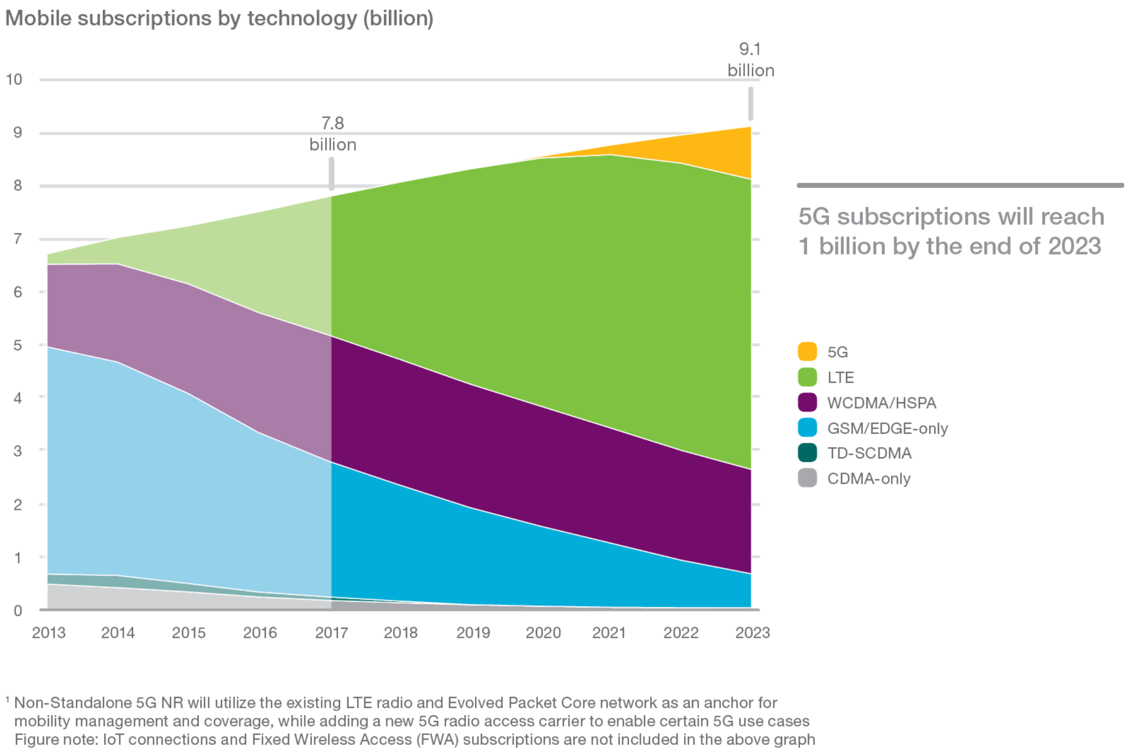


Figure 27 Mobile subscriptions (billion) by technology [Ericsson2017]

Table 6 some recent expert observations on the EMF exposure implications of these 5G NR enhancements and 5G market trends. In general, it is noted that although 5G will lead to denser network deployments and some increase in exposure levels, these levels are likely to remain within the exposure limits due to highly energy-efficient (reduced transmit power) 5G system designs.

Table 6 Some recent observations on the implications of 5G on human exposure to RF-EMF

Ref.	**Noted observations or study findings on 5G impacts on RF-EMF exposure**
[GSMA2017]	"…*There may be a small localised increase when 5G is added to an existing site or when coverage is provided in a new area. Advances in base station design and new mobile communication technologies provide higher capacity with greater efficiency. All mobile technologies, including 5G, are designed to minimise power to reduce system interference. In summary, with the addition of 5G transmitters, the total exposure to radio waves will remain very low relative to the international exposure limits*."
[Lewicki2017]	*"…Band aggregation and site sharing will be much wider implemented (in 5G heterogeneous networks) so the exposure level around many base stations may be higher…5G systems will operate in parallel with older one, so there will be increase of the exposure level at list during 5G implementation phase*"
[Frenger2017]	"*…5G NR introduces new features for enhanced (base station) energy performance…due to ultra-lean design (large base station sleep ratio and long sleep duration) and higher capacity 5G NR will add less energy than previous generations did*"
[Thors2017]	In an example study of a 5G base station using massive MIMO and beamforming "*…the largest realistic maximum power level was found to be less than 15% of the corresponding theoretical maximum.…this corresponds to a reduction in RF-EMF limit compliance distance with a factor of about 2.6*"

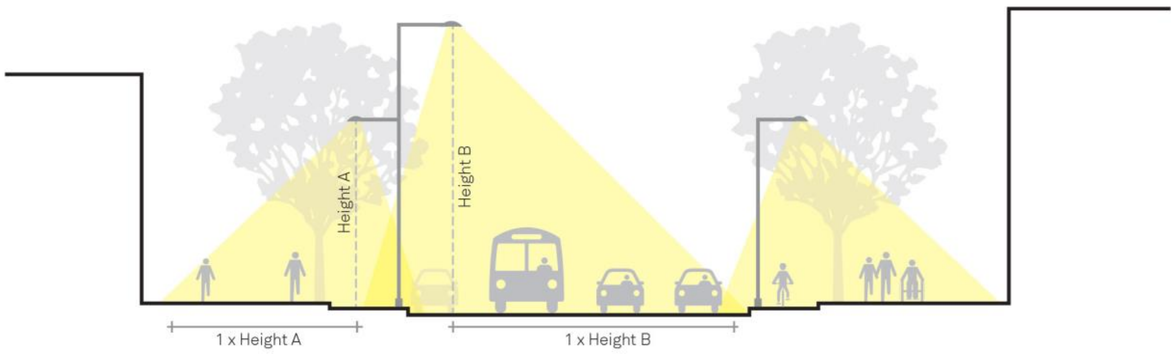
2.3.6 Historical and environmental considerations

The deployment of base station have a visual impact on the urban or rural landscape due to the visibility of antenna, radio towers, exposed cabling, baseband cabinets and so on. This has led to base stations towers and antennas to be considered as one of the prominent sources of visual pollution [Nagle2009]. Visual pollution is an aesthetic issue and refers to the impacts of pollution that impair one's ability to enjoy a vista or view. Visual pollution disturbs the visual areas of people by creating harmful changes in the natural environment. The concerns of local authorities and communities on visual pollution by base stations are particularly acute in the cases of preserving:

- Urban skyline and landscapes
- Local architectural style
- Landmarks
- Historical buildings and other heritage sites
- Parks and public gardens
- Nature reserves and conservation areas
- Areas of special scientific interest

These concerns on visual pollution and their influence on the decisions to grant planning permits for base station deployment have obliged mobile equipment vendors and MNOs to take active measures to reduce the visual impact of base stations. A common approach has been to utilise base station designs that are camouflaged or disguised to blend into buildings and other structures in the urban fabric [Masry2016, MCF2007, Nagle2009]. The antenna deployment height and physical characteristics of macro base stations (in terms of dimensions, number of equipment etc.) cause them to have more of visual impact compared to small cell base stations. However, with rollout of 5G the small cell site densities will be much higher than macro cells. Indeed as previously noted in Section 2.2.1, hyperdense deployments will constitute almost half of the small cell deployments by 2025. Moreover, a significant proportion of these deployments will also be in indoor environments.

These trends underline need for measures to minimise visual impact of small cell deployments, so as so, to ensure positive opinion from the public and local authorities on the environmental sustainability of increased densification. Small cells in urban outdoor areas are deployed at street-level and leverage the use of street furniture, such as, utility distribution poles, light poles, street signs and advertising panels. Of these structures, light poles have emerged as an interesting option the due to their targeted deployment in populated areas, as well as, their height (4.5-12 m) and inter-light pole spacing (2.5-3 times pole height) that matches well with the topologies of urban small cell networks (see Figure 28).



The spacing between light poles is typically 2.5–3 times the height of the fixture. A single row of light poles might be sufficient for a narrow street, while wider streets will require multiple rows.

Figure 28 Heights and spacing for different light poles[23]

[23] Lighting Design Guidance https://globaldesigningcities.org/publication/global-street-design-guide/utilities-and-infrastructure/lighting-and-technology/lighting-design-guidance/

To reduce possible visual impacts of small cell deployments on light poles some telecom equipment vendors are now teaming up with light pole manufacturers to produce pole designs that integrate small cells from the beginning (see contrasting examples illustrated Figure 29). Similar approaches are also being considered in the 5G-PPP Phase 2 project 5G-City[24], which includes a use case that turns cities into neutral hosts that deploy light pole small cells and edge cloud infrastructure to create dynamic end-to-end slices and lease resources to third-party operators (see Figure 30). Such cross-industry partnerships and deeper involvement of local authorities may add to upfront costs of small cell base stations but provide a very useful path for enabling environmentally acceptable network densification in the future.

(a) (b)

Figure 29 (a) Example deployment on a utility pole in Oregon (with unpainted antennas, exposed wiring and bulky baseband units) [Masry2016], (b) Fully customizable small cell pole (including pole, base, access doors, equipment, lights, etc.) [Stealth2017]

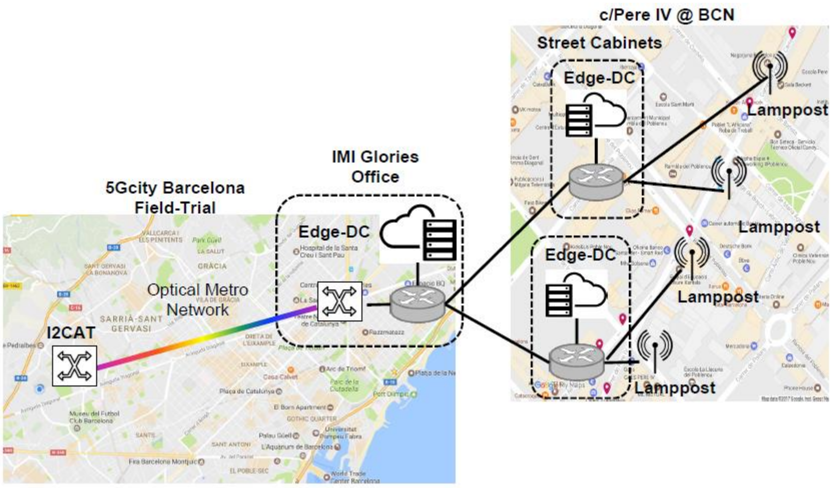


Figure 30 5GCity project Barcelona field trial

[24] http://www.5gcity.eu/

3 Stakeholder Analysis

3.1 Stakeholder identification

The small cells diverse deployment scenarios described in Section 2.1.3 (urban, enterprise, rural etc.) has implications in terms of the growing variety of stakeholders who have interests to have stake in (or express concerns about) the increased densification of small cells. This is in contrast to the era of homogeneous macrocellular network deployments, which had a fewer number of actors and clearly defined roles in the wider mobile ecosystem. A recent report by the SCF provides a vivid illustration of the expanding field of stakeholders who will stand to benefit in the growing small cell ecosystem (see Figure 31).

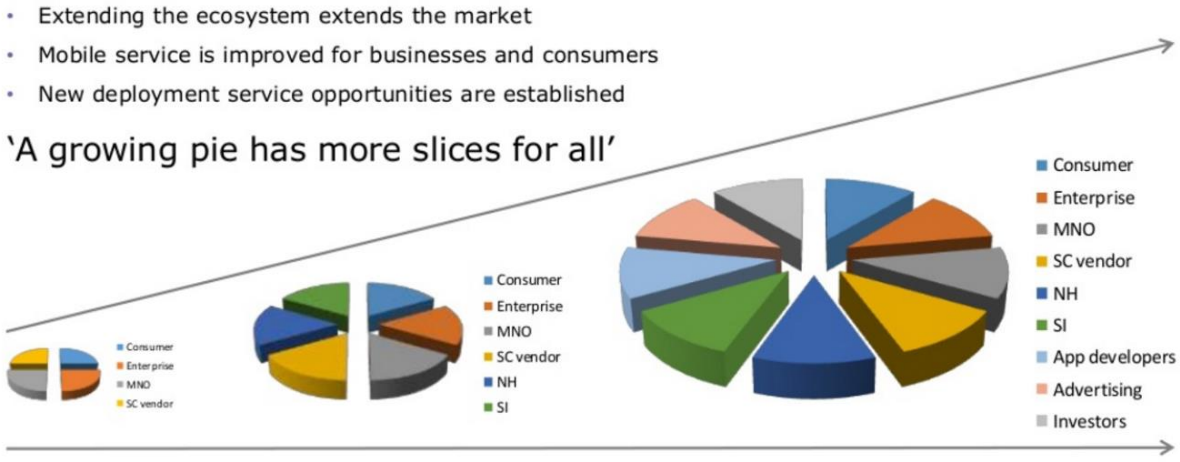


Figure 31 The evolving small cells ecosystem[25] [SCF2017c]

In this study, analysis of stakeholders attempts to assess stakeholders that reside on both sides of the argument regarding dense small cell deployments. To that end, the determination of the stakeholders from the context of dense small cell deployments involves first identifying the stakeholders and then mapping them to smaller set of stakeholder groups or categories. Consequently, four stakeholder categories are identified, namely, the **supply, demand, advocacy** and **governance** categories. The stakeholders in these respective categories are described briefly in Sections 3.1.1-3.1.4.

3.1.1 Supply Category

The supply category includes all the stakeholders that provide the assets and expertise that is necessary for planning, deploying and operating small cell networks. The key members of the supply category are listed in Table 7. The examples of different stakeholders in this category are provided in the Appendix Section 10.1.

Table 7 Brief description of supply category stakeholders

Supply category stakeholders	Relevance to dense small cell deployment
Standards development organisations (SDOs)	Responsible for specifying and maintaining (e.g. revising, promoting etc.) technical standards to harmonise development of small cell product features and ensure interoperability. These technical standards are initially voluntary but may become mandatory if they are adopted by regulators as legal requirements.

[25] Note: MNO = Mobile Network Operators; NH = Neutral Hosts; SI = System Integrators

Supply category stakeholders	Relevance to dense small cell deployment
Small cell product manufacturers or vendors	Develop and/or sell standards-based and certified (type-approved) small cell products to particular target markets.
Site owner and site facility providers	Provide suitable sites or locations (e.g. street furniture) for installation of small cells in outdoor or indoor environments. The sites may include additional facilities (e.g. power supply, backhaul) necessary for small cell operation. These facilities may be provided either by the site owner or third-party utility companies.
Mobile network operators (MNOs)	Provide communications services via deployed small cell infrastructure. The small cells may be owned by the MNO, or shared with (or leased from) third party entities (e.g. other MNOs, neutral hosts etc.). The MNOs may own some of the sites and also provide some of the needed site facilities for own use.
Neutral hosts	Entities provide small cell infrastructure for exclusive or shared use by other MNOs. Neutral hosts are different from MNOs as they themselves do not provide communications services that compete with the MNOs. The term *small cell infracos* is sometimes used to refer to neutral hosts [Casad2017].
System integrators	Third-party engineering services companies that provide small cell installation services to MNOs and neutral hosts. These companies have the necessary expertise to install small cells at different types of sites according to the small cell manufacturers' instructions. The role of system integrators may also extend to site acquisition functions.
Application developers	Individuals or companies that leverage the small cell provided application programming interface (APIs) or edge clouds to create and deliver new applications and services to individual or enterprise customers.

3.1.2 Demand category

The demand category includes the stakeholders who are the target end users of the services provided (connectivity, edge cloud etc.) via the small cells. The key members of the supply category are listed in Table 8. The examples of different stakeholders in this category are provided in the Appendix Section 10.2.

Table 8 Brief description of demand category stakeholders

Demand category stakeholders	Relevance to dense small cell deployment
Individual mobile subscribers	Individuals that subscribe to communications services provided by the MNO via small cells (e.g. private residential small cells).
Enterprises	Utilises small cells infrastructure deployed in enterprise environments (e.g. offices, retail spaces, warehouses etc.) to provide enhanced communications services to own staff or customers. The small cells may be deployed and operated either by the enterprise organisation or by third parties (e.g. MNOs, neutral hosts).

3.1.3 Governance category

The Governance category includes organisations with statutory mandates to set, implement and enforce rules or laws designed to control or govern the conduct and activities of the stakeholders from the supply group who deploy and/or operate small cells. The key members of the Governance category are listed in Table 9. The examples of different stakeholders in this category are provided in the Appendix Section 10.3.

Table 9 Brief description of Governance category stakeholders

Governance category stakeholders	Relevance to dense small cell deployment
National Governance authority (NRAs)	In general, NRA's responsible for ensuring that the mobile sector is functioning properly and that the relevant stakeholders' interests are protected in a fair and balanced manner. Specifically for this study, the NRAs are responsible for ensuring compliance with and enforcement of existing regulations related to small cell product compliance, installation and operation. The RF spectrum licensing functions vary in different countries, placing them under the NRA, or some other government agency or Ministry. However, for sake of simplicity, this report will assume all spectrum licensing is done by NRAs.
Local government	Local government is the public administration of towns, cities, municipalities, counties, districts, states and so on. Local governments are responsible for running local utilities, libraries, fire departments, public buildings, leisure facilities, parks, local law enforcement and many other areas of local everyday life. In this context, local governments are responsible for receiving and processing applications for deployment of small cells (by supply group stakeholders) in publicly owned land or infrastructure.

3.1.4 Advocacy category

The advocacy category refers to those stakeholders outside of the other three groups who provide spoken or documented opinions that are either against or in favour of dense small cell deployments. These opinions are typically targeted to the stakeholders in the other three groups and may be expressed through a number of possible channels, such as, media releases, scientific publications, organisational reports, position papers, newsletters, blog posts and other online dissemination. The key members of the advocacy category are listed in Table 10. The examples of different stakeholders in this category are provided in the Appendix Section 10.4.

Table 10 Brief description of advocacy category stakeholders

Advocacy category stakeholders	Relevance to dense small cell deployment
Environmental and historic entities	Entities (organisations or individuals) responsible for ensuring that small cell deployments and operations are implemented without adverse effects on human health, the environment or national assets of historical significance (e.g. buildings).
Industry alliances	Alliances of mobile industry stakeholders (supply side category) setup to represent; promote and advocate for the member interests. In the context of this study, the industry alliances provide a platform for defining joint positions related to facilitation of dense small cell deployment issues (to Governance stakeholders) and promotion of the use of small cells (to demand side stakeholders).
Consumer rights bodies	In general, consumer rights bodies have responsibility to ensure the rights of consumers, competition, and accurate information of the products or services in the marketplace. In the context of this study, the consumer rights of interest are those related the quality of service communications services provided by the MNOs via the mobile network (including small cells infrastructure).
Research community	Researchers and/or research projects that investigate various aspects of small cells (e.g. technical, commercial, legal, etc.) to produce new scientific knowledge and innovations. These may inform or influence the small cells-related perceptions, decisions or developments (by all other

Advocacy category stakeholders	Relevance to dense small cell deployment
	stakeholders).
Technology analysts	Individuals or firms that provide expert advice on small cell technologies and trends to all other relevant stakeholders.

3.2 Stakeholder assessment

The assessment of the stakeholders identified in Section 3.1 is conducted by addressing the following aspects related to dense small cell deployments, from the perspective of each stakeholder:

- What is of interest or importance to the stakeholder? [*Interests*]
- How could the stakeholder influence positively (take the initiative, encourage or promote) dense small cell deployments? [*Positive influence*]
- How could the stakeholder influence negatively (impede or prevent) dense small cell deployments? [*Negative influence*]

The assessment of the stakeholders is implemented using stakeholder analysis matrices and is summarised separately for each stakeholder categories in the remainder of this subsection.

3.2.1 Assessment of supply category stakeholders

The assessment of the individual stakeholders of the supply category are listed in Table 11.

Table 11 Summary assessment of supply category stakeholders

Supply category stakeholders	Interests	Positive (+) influence	Negative (–) influence
Standards development organisations (SDOs)	• Interoperability • Backward/forward compatibility • Global technology harmonisation	+ Provide economies of scale for small cell products + Enable small cell product development for different markets	
Small cell product manufacturers or vendors	• Increase number of small cell shipments • Expand markets to new types of customers (e.g. building owners, fleet owners etc.)	+ Ensure product compliance with local regulations + Develop small cell products for new deployment scenarios + Develop small cell products for simpler installation	– Reluctance to customise small cell products to comply with regulations of certain markets
Site owner and site facility providers	• Increase revenue from site rental fees • Increase revenue from lease of site facilities	+ Simplify rights of way procedures + Invest in site facilities ahead of demand	– Overpriced fees for sites or leased facilities
Mobile network operators	• Increased subscriber numbers or subscriber retention	+ Deploy small cells to enhance network capacity and/or	– Reluctance to share infrastructure with competitors

Supply category stakeholders	Interests	Positive (+) influence	Negative (–) influence
(MNOs)	• Differentiation through enhanced network performance and new service types • Reduce network capital and operational costs	coverage + Plan and optimise networks to comply with coverage commitments and local regulations + Share small cell infrastructure with other MNOs	– Delays in upgrading (due to lack of competitive pressure)
Neutral hosts	• New revenue streams from leasing small cell infrastructure • Increase value of existing assets (e.g. buildings)	+ Reduce small cell deployment burden for MNOs + Provide more appealing option for sharing small cell infrastructure (compared to MNO deployments)	
System integrators	• Increased revenue with number of small cell installations	+ Enable scalable and rapid small cell deployments + Ensure installation compliance with regulations	
Application developers	• Create new revenue streams from small cell apps (e.g. through usage fees, advertisements etc.)	+ Increase added value of small cells to end users beyond mere connectivity benefits + Provide further incentive for deployment of small cells around user surroundings	

3.2.2 Assessment of demand category stakeholders

The assessment of the individual stakeholders of the supply category are listed in Table 12.

Table 12 Summary assessment of demand category stakeholders

Demand category stakeholders	Interests	Positive (+) influence	Negative (–) influence
Individual mobile subscribers	• Improved quality of service • New service offerings • Affordability of services	+ Demand high service quality at all locations + Self-install small cells (e.g. in private residence)	
Enterprises	• Increased productivity, creativity, responsiveness and customer satisfaction • Improved quality of service throughout	+ Facilitate small cell deployments in enterprise environments to third-parties (e.g. neutral hosts, MNO) + Self-installation and	

Demand category stakeholders	Interests	Positive (+) influence	Negative (–) influence
	enterprise environments • Enterprise-grade security and device management • Save costs of enterprise wireless networks	operation of enterprise small cells	

3.2.3 *Assessment of governance category stakeholders*

The assessment of the individual stakeholders of the governance category are listed in Table 13.

Table 13 Summary assessment of governance category stakeholders

Governance category stakeholders	Interests	Positive (+) influence	Negative (–) influence
National regulatory authority (NRAs)	• Ensure competitiveness of the sector • Protect and balance interest of different stakeholders • Ensure safe and secure operating environment	+ Enforce competitive environment to allow deployments by diverse stakeholders + Facilitate spectrum availability for small cells operations	– Stringent or inflexible regulations for small cell installation and operation – Delays in updating regulations to fit with new technical developments
Local government	• Properly maintain public infrastructure and land • Generate sufficient revenue for local administration and service delivery • Enforce local law and rules • Ensure local safety and security	+ Provide single point of contact for acquisition of small cell sites on public infrastructure and land	– Inconsistencies in administrative processes and fees for siting permits across local governments – Prolonged approval processes for siting permits – Overpricing or unsustainable site rental fees

3.2.4 *Advocacy category stakeholders*

The assessment of the individual stakeholders of the advocacy category are listed in Table 14.

Table 14 Summary assessment of advocacy category stakeholders

Supply category stakeholders	Interests	Positive (+) influence	Negative (–) influence
Environmental and historic entities	• Protect and enhance the human environment • Conserve and protect assets of historical significance	+ Drive innovations in small cell product design (e.g. camouflaged designs, product embedding in	– Put pressure on regulations and siting permits against dense small cell deployments due to

Supply category stakeholders	Interests	Positive (+) influence	Negative (–) influence
	• Influence policymaking and regulation on issues affecting environment	everyday objects etc.)	environmental or historical concerns
Industry alliances	• Protect the interests of supply side stakeholders • Ensure health and growth of the mobile sector • Provide platform for industry groups to agree on and present common positions (e.g. towards policy makers and regulators) • Inform and promote benefits of new technologies and innovations towards all other stakeholder groups	+ Advocate for benefits of dense small deployments and provide clarifications against opposing arguments + Influence standardisation, regulation and policy making in related small cells + Identify new small cell driven business opportunities for stakeholders both within and outside the alliance	
Consumer rights bodies	• Ensure the rights of subscribers • Ensure fair competition (choices for subscribers) • Ensure accuracy of information (e.g. adverts) of the products or services in the marketplace	+ Drive denser deployments of small cells to ensure service quality at all locations matches advertised rates etc.	
Research community	• Scientific or technical excellence (e.g. number of citations etc.) • Commercial exploitation of innovations • Maximise societal impact of research results	+ Propose new approaches, technologies or scientific breakthroughs that enable increasingly dense small cell networks + Produce scientific evidence that supports dense small cell deployments	– Highlight with scientific evidence the concerns against dense small cell deployments
Technology analysts	• Analyse and correctly predict industry trends • Generate and commercialise strategic knowledge (e.g. high value opportunities)	+ Advise supply side stakeholders on small cell densification strategies to ensure commercially sustainable deployments	

4 Regulatory Factors Impacting Dense Small Cell Deployments

4.1 Background

4.1.1 Need for effective regulatory framework

A liberalised mobile sector requires regulation, not as an end in itself, but as a means to foster effective competition, protect consumer interests, prevent market failure, manage usage relevant resources (e.g. spectrum) and increase access to technology and services [ITU2011]. In Europe, the **EU's regulatory framework for electronic communications**[26] constitutes a series of rules, which apply throughout the EU Member States. This package includes five Directives and two Regulations:

- Framework Directive (based on Framework Directive 2002/21/EC and Better Regulation Directive 2009/140/EC)
- Access Directive (based on Access Directive 2002/19/EC and Better Regulation Directive 2009/140/EC)
- Authorisation Directive (based on Authorisation Directive 2002/20/EC and Better Regulation Directive 2009/140/EC)
- Universal Service Directive (based on Universal Service Directive 2002/22/EC and Citizens' Rights Directive 2009/136/EC)
- Directive on Privacy and Electronic Communications (based on the Directive on Privacy and Electronic Communications 2002/58/EC, the Amending Directive 2006/24/EC and the Citizens' Rights Directive 2009/136/EC)
- Regulation on Body of European Regulators for Electronic Communications (BEREC)
- Regulation on roaming on public mobile communications networks

In September 2016, the European Commission published legislative proposals to establish the European Electronic Communications Code (EECC) [EC2017], as well as, an action plan to deploy 5G across the EU as from 2018. The draft directive establishing the EECC proposes a merger of the four aforementioned telecom directives. The objective of the proposal is adopt the EU regulatory framework to the changes in digital environment and new modes of consumption. Among the EECC objectives is need to promote the availability and take up of 'Very High Capacity' (VHC) connectivity, which in practice can be enabled in part by dense small cell deployments. The EECC makes specific reference to small cells (referred to as '*small-area wireless access points*' in EECC) in Article 56, which states that in the deployment and operation of small cells:

1. *Competent authorities shall allow the deployment, connection and operation of unobtrusive small cells under the general authorisation regime and shall not unduly restrict that deployment, connection or operation through individual town planning permits or in any other way… The small-area wireless access points shall not be subject to any fees or charges going beyond the administrative charge that may be associated to the general authorisation*.
2. *In order to ensure the uniform implementation of the general authorisation regime for the deployment, connection and operation of small cells, the Commission may, by means of an implementing act, specify technical characteristics for the design, deployment and operation of small cells, which shall at a minimum comply with the requirements of Directive 2013/35/EU[1] and take account of the thresholds defined in Council Recommendation No 1999/519/EC[1] [EC]. The Commission shall specify those technical characteristics by reference to the maximum size, power and electromagnetic characteristics, as well as the visual impact, of the deployed small cells. Compliance with the specified characteristics shall ensure that small cells are unobtrusive when in use in different local contexts*.

In general, the implementation of an effective regulatory framework (in EU and elsewhere) provides a

[26] https://ec.europa.eu/digital-single-market/en/telecoms-rules

number of benefits to the mobile sector and ICT industry. These benefits and their potential implications from a dense small cell deployment perspective are summarised in Table 15.

Table 15 Benefits of effective regulatory framework from a small cells perspective

Benefits of effective regulatory framework	Small cells perspective
Better quality of service	The UEs connected to small cells generally have a better quality of service. This is typically due to improved performance (e.g. SINR, Gbps/km^2) in areas of poor macro coverage and/or hotspots with high density of UEs (see Section 2.1.3). The small cells also provide "offloading gain" for macro connected UEs by reducing number of UEs served by macro base stations. The quality of service increases with the network densification, underlining the need for regulation that facilitates denser deployments.
Higher (service) penetration	Small cells enable increased service penetration by influencing service adoption through improved perception of quality of service and user experience. Furthermore, small cells enable more affordable services due to reduced capital and operational costs (less cost per transmitted bit). As above the regulation that facilitates denser deployments is essential.
More rapid technological innovation	The development of edge cloud computing, network slicing and small cell service APIs will transform small cell base stations from mere broadband radio access points to application and service innovation platforms (as noted in Section 2.1.2). A regulatory framework that supports innovation would ideal in this case.
Increased investment[27]	The diversity of stakeholders able to deploy or own small cells (see Section 3.1) increases the number of potential investors in mobile infrastructure (beyond traditional MNOs). The regulatory environment is a critical factor in their decision to invest in a particular region or country.
Greater economic growth	The socio-economic benefits of 5G will considerable across a number of vertical industry sectors.[28] The dense deployment of small cells are among the critical network enhancements necessary for 5G to fulfil the KPIs demanded by the new use cases of these verticals.

4.1.2 Differences in macro and small cell base stations

The regulations for installation and operation of mobile infrastructure were originally specified for homogeneous networks with mostly macro base station deployments. However, the increasingly heterogeneous networks with the number of small cells base stations far exceeding macro base stations is highlighting the need for reformulation of some of the regulations, to obtain a regulatory framework that provides the benefits listed in Table 15. The core arguments for these regulatory updates is built on fundamental differences between small cell and macro base stations, as summarised in Table 16.

[27] The EC estimates that achievement of the Gigabit Society (by 2025), will require overall investment (in mobile and fixed technologies) of €500 Billion over the coming decade, €155 Billion above current operators' investment trends.
[28] For instance, in Europe benefits of introducing 5G are expected to reach €113.1 billion per year by 2025 for just in four vertical sectors: automotive, health, transport and energy [EC2016]

Table 16 Differences in macro and small cell base stations that may influence regulation

Attribute	Macro base stations	Small cell base stations
RF transmit power[29]	High (typically 43-48 dBm)	Low/medium (≤ 38 dBm)
Antenna installation height	Typically 10-60m above ground	Typically ≤10m above ground (or indoor floor level)
Coverage range	Several km to few tens of km	Several meters to few hundred meters
Spectrum	Licensed spectrum in low (<1 GHz) and mid (1-6 GHz) bands	Licensed or unlicensed spectrum in low (<1 GHz), mid (1-6 GHz) and high (6 GHz) bands
Power consumption	High (1-5 kW)	Low/medium (5-400 W)
Deployment density	Few sites per square km	Tens or hundreds of sites per square km
Deployment locations	Outdoor radio towers or on building rooftops	Outdoor below rooftop or at street level, indoor in-building, vehicular platforms etc.
Physical characteristics	Typically separate discrete equipment (antennas, antenna cabling, baseband units, cooling systems etc.)	Relatively smaller dimensions, integrated packaging (built-in antennas), convection cooled
Base station owners	MNOs	MNOs, neutral hosts

Section 4.2 presents a brief review and analysis of some of the existing regulations and related factors that may impact the dense deployment of small cells.

4.2 Review of the key regulatory factors/issues from small cells perspective

4.2.1 General definition or classification of small cells

The differentiation in regulations for small cell and macro base stations is contingent on the explicit definition or classification of the different base station types in regulations. Lack of this distinction would place small cells under the same (more stringent) regulations as macro base station. In the case that the classifications of base stations do exist, there may still be challenges due to differences in what would qualify as a small cell across different regulatory regimes. This fragmentation would complicate the process of deployment of small cells, particularly for operators who carry out nationwide or multinational network deployments. Furthermore, the ambiguity in the definition of small cells also reduces effectiveness of governance stakeholders in ensuring that only installations that qualify as small cell base stations are eligible for any regulatory concessions (in this context, some interesting examples of deployment cases are provided in [Masry2016] and Figure 32).

[29] 3GPP rated output power

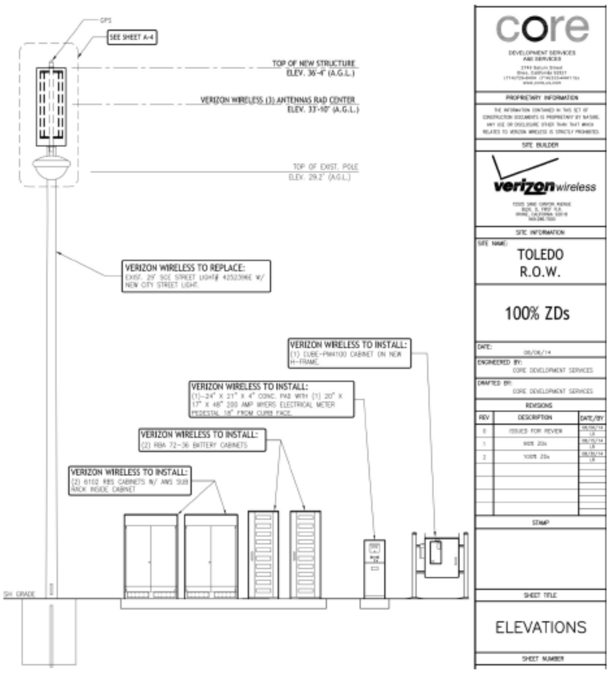


Figure 32 An example application for a small cell deployment with multiple co-deployed cabinets that may obstruct public right-of-way [Masry2016]

Therefore, the adoption of standardised definitions and classification of small cells is crucial step for facilitating rapid deployment of small cells but also ensuring regulatory compliance. A common approach for base station classification is through basis of installation classes derived from parameters, including transmit power, effective isotropic radiated power (EIRP), antenna installation height and installation location (outdoor or indoor). A number of standards have been specified by various SDOs, to reduce inconsistencies in the selection of classification parameters in different regulatory regimes. The notable ones are:

- Base station classes of 3GPP TS 36.104 based on transit output power of a single antenna (described previously in 2.3.3 and [3GPP2017]);
- Base station installation classes specified by ITU in standards ITU-T K.52 [ITU-T2016] and K.100 [ITU-T2017b] that are based on the EIRP and antenna installation height;
- Base station installation classes of the IEC 62232 Ed.2.0 guidelines [IEC2017], which use same criteria (EIRP and antenna installation height) as ITU standards above but also provide more detailed elaboration on technical rationale and evaluation approaches.

The currently consensus seems to be building around the IEC 62232 Ed.2.0 guidelines as the preferred classification method. Further details on this trend and the IEC guideline will provided in Section 4.2.3 in the context of RF-EMF exposure limits.

4.2.2 Regulatory implications on sharing of small cells

The implications regulatory frameworks in terms of limiting, encouraging or mandating the sharing of small cell infrastructure (as described Section 0) has been previously analysed in a number of studies including [Ghanbari2013, Neumann2017, SCF2016b]. The formulation of network sharing policies by NRAs has been informed by EU directives (described in 4.1.1), as well as, the need to strike a balance on a number of factors related to network sharing (illustrated in Figure 33) so as to:

- Prevent distortion or restriction of competition;
- Promote and ensure efficient use of necessary but limited resources (e.g. spectrum);
- Ensure a competitive environment for the benefit of consumers; and
- Promote efficient investment and encourage innovation in new/improved infrastructure.

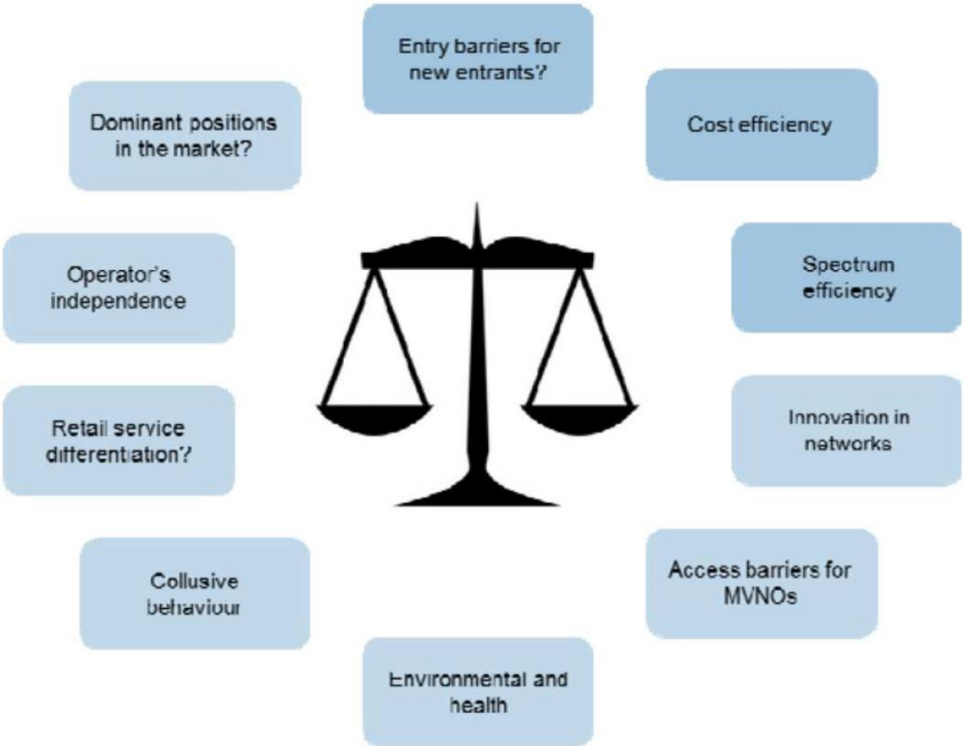


Figure 33 Factors that may influence regulatory decisions regarding sharing arrangements [Ghanbari2013]

A factor that has significant impact on the implementation feasibility of the active sharing of small cells is the existence of regulations that permit or even oblige spectrum sharing in particular [SCF2016b]. Currently there are diverse range of spectrum authorisation and assignments used in different countries. A recently completed study SMART 2016/0019 on spectrum assignment in across different EU Member States provides classification of seven spectrum access types (see Table 17) [EC2017b]. Among these spectrum access types are newer approaches that create possibilities to make spectrum available for small cell providers without licensed spectrum (neutral hosts).

One option is the use of Licensed Shared Access (LSA), whereby, an incumbent spectrum license holder (e.g. MNO) may license the use of their spectrum to a third party (e.g. neutral host), in locations were the spectrum is unused by the incumbent. Whilst the use of LSA seems promising for enabling sharing of small cells, the SMART 2016/0019 noted from extensive with national regulators and MNOs that "…*Member States do not widely use Licensed Shared Access (LSA) as an authorisation approach. Scepticism still prevails on LSA and the associated administrative burden*." [EC2017b]

Table 17 Definitions of different spectrum access types [EC2017b]

Type of spectrum access	Details and examples	General authorisation ^	Individual right of use ^	Collective use	Exclusive use	Users must notify or get licence	Regulator controls usage	Fees #	Charges ∞
1. Licence exempt	Open access for certified devices E.g. low power Wi-Fi, SRDs, mobile user equipment , VSAT users	★★★★★		✓	✖	✖	✖	✖	✖
2. Light licencing (nominal)	As above but licence or notification required. E.g. Some PMSE usage; radio amateurs; High power outdoor Wi-Fi	★★★★	★	✓	✖	✓	✖	✓ or ✖	✖
3. Light licensing (restrictive)	As above but includes individual frequency co-ordination and restrictions on number of users E.g. some SAP services; UK 1800 MHz DECT guard band	★★★	★★	✓	✓ or ✖	✓	✓	✓ or ✖	✓ or ✖
4. Private commons	The exclusive licensee gives access to its spectrum under specified conditions.	★★★	★★	✓	✖	✖	✖	✓	✓
5. Dynamic Spectrum Access (DSA)	Incumbent grants automated short term access for third party using database or sensing. E.g. TV white space	★★	★★★	✓	✖	✓ or ✖	✓ or ✖	✓ or ✖	✓ or ✖
6. Licensed shared access (LSA)	Access granted to a third party by an incumbent user, typically a government body.	★	★★★★	✓	✖	✓	✖	✓	✓
7. Exclusive individual licensing	Exclusive rights to specific portion of spectrum for individual user. E.g. mobile licences		★★★★★		✓	✓	✓	✓	✓

Table 1: Definitions of different spectrum access types

Key

^ Star system indicates the characteristics of the licencing type. e.g. four stars for general authorisation and one star for individual rights of use indicates that Light licensing (nominal) is most similar to the general authorisation approach.
Payments designed to recover administrative costs
∞ Payments designed to distinguish between competing operators and increase spectrum efficiency e.g. payments made at spectrum auctions

Another emerging spectrum access possibility that could facilitate the sharing of small cells is the use of license exempt (unlicensed) spectrum for operation of small cells. Small cells operating in the license exempt bands require no fee to be paid, but must adhere to certain harmonised technical and operational conditions (e.g. RF transmit power, bandwidth etc.), to avoid causing harmful interference to other equipment operating in the same band. The LTE-LAA mechanisms standardised from 3GPP Release 13 onwards specify Listen-Before-Talk (LBT) mechanisms for LTE small cells to co-exist with Wi-Fi systems in the 5 GHz band already populated by Wi-Fi devices.

However, the use of LAA is limited by the need for use of a primary component carrier in the licensed band to serve as the connectivity anchor whilst the 5 GHz only provides secondary carriers. Alternatively, the MulteFire Alliance[30] proposes an approach that also enables the use of license exempt bands (e.g. 5 GHz) for the primary carriers for LTE small cells. To that end, MulteFire specifications consider a “neutral host use cases” whereby a MulteFire small cell may utilise the license exempt band to serve subscribers of the MNOs that are sharing the small cell. A number of vendors are expected to bring MulteFire small cell products into the market in year 2018 following the completion of the MulteFire specifications in 2017.

The issue of mobile network sharing is one that is also highlighted in the draft EECC directive, whereby, Article 59(3) states:

[30] https://www.multefire.org/

> *Member States shall ensure that **national regulatory authorities have the power to impose on undertakings providing or authorised to provide electronic communications networks obligations in relation to the sharing of passive or active infrastructure**, obligations to conclude localised roaming access agreements, or the joint roll-out of infrastructures directly necessary for the local provision of services which rely on the use of spectrum, in compliance with Union law, where it is justified on the grounds that,*
>
> a. *The replication of such infrastructure would be economically inefficient or physically impracticable, and*
> b. *The connectivity in that area, including along its main transport paths, would be severely deficient, or the local population would be subjected to severe restrictions on choice or quality of service, or on both*.

The views of the incumbent spectrum and infrastructure owners (MNOs and their industry alliances) on the sharing or access obligations have general called for re-evaluations of some of elements of the aforementioned Article 56(3) and advocated for voluntary sharing. These views are mostly attributed to concerns on negative impacts on investment decisions due to unpredictability or uncertainty of future sharing decisions.

Table 18 Snapshot of views on obligated sharing or access of Article 56(3) of EECC

Ref.	**Excerpt views on EECC Article 56(3) from position papers**
European Telecommunications Network Operators' Association (ETNO) [ETNO2017]	"…*The same article introduces new symmetric obligations on mobile (art. 59.3) in the form of network sharing. We believe that these should be removed. Mobile markets have functioned well and have become growingly competitive in the absence of regulation and we see no need to revert this situation and create more uncertainty with the EECC.*"
GSM Association (GSMA) [GSMA2016b, GSMA2017b]	"…*This provision jeopardizes the level of certainty, predictability and consistency that the EECC tries to create, and which are essential for investors. Mobile markets are fiercely competitive absent regulation, and various forms of network sharing occur on a voluntary basis in many Member States. Mobile licenses represent a very high level of investment - founded on anticipated efficient business - along with commitments taken during the process, notably on coverage. The imposition of roll out and/ or sharing or access obligations post spectrum award would have a very significant negative impact on the industry and introduces a tremendous amount of uncertainty, contrary to the principle of legitimate expectation created by the license award*."
Orange [Orange2017]	"…*The mobile sector is highly dynamic, with mobile operators competing through investment in more coverage and new technology. Their obligations are set in their licence which, on the basis of substantial fees, gives them legitimate confidence in their conditions of operations. Despite this situation, the draft Code introduces in article 59.3 a provision allowing regulators to impose mobile networks sharing and joint roll out. This inclusion must be reconsidered; ex-post sharing obligations would reduce investment incentives, limit operators' competition on coverage, and contradict agreed commitments. Sharing arrangements should only be voluntary, possibly under the monitoring of the regulator.*"

The network sharing enhanced through virtualisation of network functions using SDN and NFV, will become increasingly prevalent as the adoption of 5G increases. This will open the field to new cloud-based players who will operate (physical and/or virtual) network functions for themselves or as a service to other MNOs, neutral hosts, industry verticals and so on. There are many innovations (business, technologies, services etc.), as well as, performance and cost related benefits for providers and consumers of these network functions. However, these developments also provide new challenges for regulation. The current regulatory framework needs to be extended to regulate these new network operators or services providers in this emerging ecosystem. Moreover, in this software-driven, virtualized and highly diversified networking environment there are emerging risks that regulation may need to mitigate against to ensure, among other things, interoperability, privacy and security, net neutrality and fair competition.

The draft EECC directive has also noted SDN and NFV as being among the developments whose adoption "…*expose the current rules to new challenges that are likely to increase in importance in the medium and long term, and therefore must be factored into a review of the regulatory framework for electronic communications*" [EC2017]. The regulatory and policy implications of these SDN/NFV driven developments have been recently analysed in a study (SMART 2015/0011) for the EC [EC2017c]. Among the SMART 2015/0011 study findings, is the noted need for policy and regulatory preparedness to the uncertainties of the effects and implications of the SDN/NFV developments, as indicated in the SWOT (strengths, weaknesses, opportunities and threats) analysis of Figure 34.

Strengths	Weaknesses
• Early and substantial support for technological innovation e.g. in Horizon2020 • European Commission's efforts in facilitating the development of 5G • General pro-investment direction of European telecommunications regulatory framework • Digital Single Market as an important framework for new cross-border digital services	• Regulatory framework may be too static for accelerating technological development
Opportunities	**Threats**
• Side-by-side development of open-source and industry standards • Digitisation economic and societal potential	• Resistance from legacy actors • Challenges in terms of change management • Uncertainty about the effects, impact, and implications of SDN and NFV

Figure 34 SMART 2015/0011 SWOT analysis of the policy and regulatory framework for SDN/NFV [EC2017c]

4.2.3 RF-EMF exposure limits

The requirement for compliance assessment of small cells in terms of RF-EMF exposure limits may present one of the most significant barriers for rapid and sustainable network densification, due to the relatively larger number of small cell sites (both outdoor and indoor) that may need to undergo the assessment.

The compliance assessment of base station products is generally based on the evaluation of the RF-EMF at different phases as described in IEC 62232 Ed.2.0 guidelines [IEC2017]. These different assessment phases are summarised below.

1) *Product compliance*: This is a requirement for base station manufacturers or vendors to provide the RF exposure information for the base station product, which includes the relevant compliance boundary (exclusion zone) information for the product to be assessed against local regulations and get approval to appear on the market.

2) *Product installation compliance*: This is a requirement for the network operator or other entity

deploying a base station product to evaluate the total RF-EMF exposure levels in accessible areas and in the vicinity of the installed base station product, to verify compliance with relevant local regulations before the product is put into service. In this evaluation, the contributions from other RF sources in the area and possible effects of the surround environment may need to be taken into consideration in the evaluation. The overall RF exposure levels could be determined using measurements or computations and aggregating the RF exposure levels from the different sources in the vicinity.

3) *In-situ RF exposure assessment*: This involves measurement of in-situ RF exposure levels in the vicinity of an base station installation after the base station product has been taken into operation. The measurement process shall identify all emitting sources in the surrounding measurement area and include them in the post-processing. These in-situ measurements may be required to determine during the operational phase if the RF exposure levels remain in compliance with local regulation or gather RF exposure data for communication to various stakeholders.

The product installation compliance and in-situ RF exposure assessments are routine processes for macro base stations. However, the significant majority of future base station deployments will be for small cells, whose low transmit powers are well within the ICNIRP RF exposure limits, even considering the fact that small cells deployed much closer to humans at street-level, inside buildings and so on (as noted in Section 2.1.3).

Therefore, there has been increased recommendations (backed by empirical research results) for small cells to have simplified assessments that reduce or eliminate the need for product installation compliance (see Figure 35). This would imply small cells only requiring one time approval for product compliance when a new small cell product is introduced to the market and removes the requirement to assess individual small cell installations. However, the opportunity for regulators to conduct random audits of compliance could continue through in-situ RF exposure assessment of areas around small cell sites.

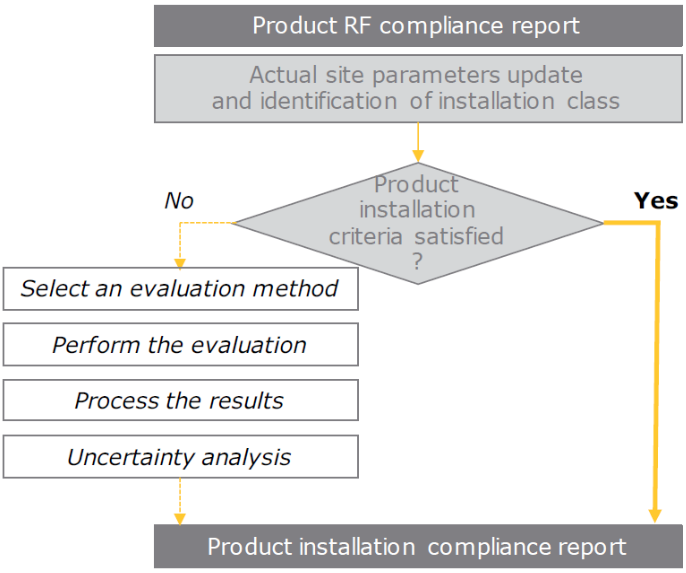


Figure 35 Simplification in the product installation compliance [SCF2017]

Table 19 presents a sample of research studies comparing the level human exposure from small cells and macro sites, where in most cases it is noted that the RF exposure levels from small cells are low even when deployed indoors a few meters form the users. Furthermore, some of the studies noted that the short radio link from a user to the small cells would reduce the required transmit power of user devices (e.g. smartphones) thus reducing further localised RF exposure levels from users' handheld or wearable devices. Moreover, the realistic spatio-temporal traffic variations, as well as, time-division duplexing (TDD)[31], power optimisation for intercell interference management, savings in energy consumption (e.g. discontinuous transmission, idle cell switch-off) and other performance-enhancing mechanisms aggressively employed in small cell networks [Holma2016] would mean that the small cell transmit powers in practice are well below the theoretical maximum powers. As a result, the compliance boundaries typically evaluated based on these theoretical maximum transmit powers creates overly conservative EMF limits and may put severe constraints on density of small cell deployments.

Table 19 Example research conclusions from study of compliance of small cells to EMF limits

Ref.	RAT(s), band	Deployment scenarios	Evaluation Methodology	Excerpt from study conclusions
[Cooper2006]	GSM, 900 MHz, 1800 MHz	Outdoor	Measurements	"…*On the basis of the results from measurements and calculations, members of the public would not be exposed in excess of the ICNIRP guidelines whilst standing on the ground near any of the representative microcell base stations*."
[Zarikoff2013]	UMTS, 1900-2100 MHz	Indoor	Measurements Computations	"…*In general, our results demonstrate that only in cases of excessive distance between the mobile user and the femtocell will the user experience more exposure then if connected to the macrocell*."
[Aerts2013]	UMTS 1900-2100 MHz	Indoor	Measurements	"…*It is found that, unless the mobile phone is not used, even for an average macrocell coverage, the deployment of a femtocell base station could drastically reduce the user's RF-EMF exposure…*"
[Aerts2015]	GSM 1800 MHz	Indoor (train)	Measurements	"…*we found that by connecting to a small cell, the brain exposure of the user could realistically be reduced by a factor 35 and the whole-body exposure by a factor 11….whether the total human RF-EMF exposure in the train due to mobile communications is reduced by the deployment of a small cell ultimately depends on several factors, including the output power of the small cell, the number of small cells in the train…*"
[Thielens2017]	n/a 3500 GHz	Indoor	Measurements Computations	"…*We conclude that attocells are an interesting solution to provide high-bandwidth coverage while maintaining low exposure to RF EMF fields for the users*."

[31] In TDD, the downlink transmissions are separated from the uplink transmission by allocation of different time-slots within the same frequency band. From an RF-EMF exposure perspective, this means that emissions from small cells (downlink) only happens for a fraction of time. For LTE-TDD systems this fraction ranges from 0.4 to 0.9, whereas for 5G TDD it is roughly 0.75 [THORS2017].

A number of guidelines are also emerging from different SDOs for simplification of assessment and installation of small cells. The ITU-T Study Group 5 in has proposed (in the ITU-T K.52 standard) three classes for emitter installations, namely [ITU-T2016]:

1) *Inherently compliant*: These are installations that do not require any particular precautions because they produce EMF that comply with relevant exposure limits a few centimetres away from the source. According the guidelines sources that have an EIRP less than 2W are considered by default to be inherently compliant.

2) *Normally compliant*: Installations with sources that produce EMF that may exceed relevant exposure limits but are not accessible to general public under normal conditions (e.g. antennas mounted on sufficiently tall towers or narrow-beam earth stations pointing at satellite). Precaution may be needed by who are authorised to be in the vicinity of the emitter.

3) *Provisionally compliant*: These are installations that require special measures to achieve compliance. Sites that do not meet the conditions for normally compliant classification are considered provisionally compliant.

According to ITU-T K.52 guidelines, the sites where the assignment of these categories is ambiguous, additional calculations or measurements will need to be required.

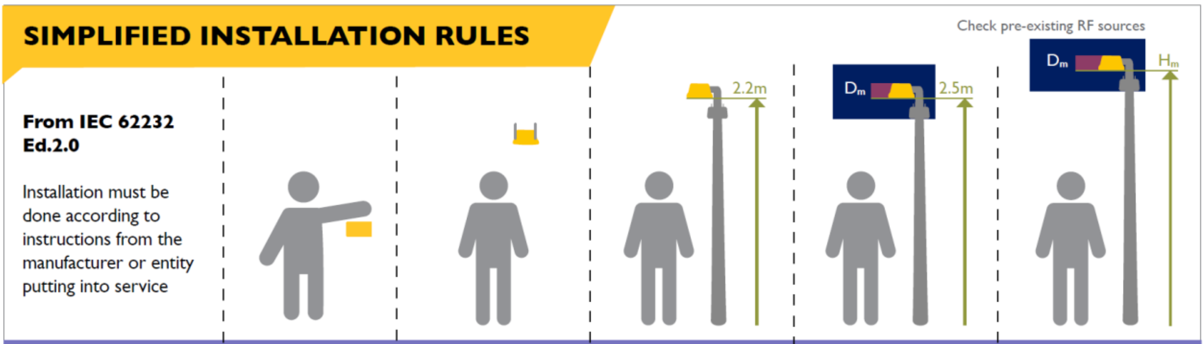
The IEC has also proposed even more simplified installation rules for low power base stations products via the **IEC 62232 Ed.2.0 standards** [IEC2017]. To that end, the IEC guidelines propose product installation classes (see Table 20) for which a simplified installation evaluation process is applicable based on ICNIRP exposure limits [ICNIRP1998]. The parameters and attributes used to define the product installation class include the EIRP[32], antenna directivity, and position of antenna relative to areas accessible by the general public and compliance boundary specified for the product. The ITU-T recommendations for simplified installation were also updated in 2017 through ITU-T K.100 standard to be aligned to the IEC 62232 Ed.2.0 guidelines [ITU-T2017b]. Similar processes has been initiated for the adoption of IEC 62232 Ed.2.0 as a reference technical standard for the implementation of the EU Radio Equipment Directive (RED) 2014/53/EU[33] for base stations [SCF2017].

[32] In this context, the EIRP is from power transmitted by the installed antenna(s) including all active bands of the base station product. A distinction is made from the 3GPP base station classes whose classification based rated power output is only quoted for power at the connector (input) of base station antenna [3GPP2017]
[33] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC (OJ L 153, 22.5.2014, p 62). http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0053&from=EN

Table 20 IEC product installation classes where a simplified evaluation process is applicable [IEC2017]

Class	*EIRP*[a] (W)	*EIRP* (dBm)	Product installation criteria
E0	n/a	n/a	The product complies with IEC 62479 or the product compliance boundary dimensions are zero. No specific requirement for product installation.
E2	≤ 2	≤ 33	The product is installed according to instructions from the manufacturer and/or entity putting into service. Compliance with the exposure limits is generally obtained at zero distance or within a few centimetres.
E10	≤ 10	≤ 40	The product is installed according to instructions from the manufacturer and/or entity putting into service and the lowest radiating part of the antenna(s) is at a minimum height of 2,2 m above the general public walkway.
E100	≤ 100	≤ 50	The product is installed according to instructions from the manufacturer and/or entity putting into service and: (a) the lowest radiating part of the antenna(s) is at a minimum height of 2,5 m above the general public walkway, (b) the minimum distance to areas accessible to the general public in the main lobe direction is D_m [b], and (c) there is no pre-existing RF source with *EIRP* above 10 W installed within a distance of 5 D_m metres in the main lobe direction (as determined by considering the half power beam width) and within D_m metres in other directions. D_m is the compliance distance in the main lobe assessed according to 6.1. If D_m is not available, a value of 2 m can be used or 1 m if all product transmit frequencies are equal to or above 1 500 MHz.[c]
E+	> 100	> 50	The product is installed according to instructions from the manufacturer and/or entity putting into service and: (a) the lowest radiating part of the antenna(s) is at a minimum height of H_m metres above the general public walkway, (b) the minimum distance to areas accessible to the general public in the main lobe direction is D_m [b] metres, and (c) there is no pre-existing RF source with *EIRP* above 100 W installed within a distance of 5 D_m metres in the main lobe direction and within D_m metres in other directions. D_m is the compliance distance in the main lobe assessed according to 6.1 and H_m is given by Equations (6.1), (6.2) or (6.3).[d]

The IEC 62232 Ed.2.0 product installation classes have also formed the basis of recommendations for simplified small cell installation rules from the SCF [SCF2017] and GSMA [GSMA2016] (see Figure 36). At the lower end of the scale is the installation class E0 that typically refers to the 'touch compliant' residential small cells, which can be self-installed at home by residents, in the same way as Wi-Fi access points (see Figure 37a). At the opposite end of scale is the end of the scale is the E+ installation class whose aggregate EIRP may exceed 100 W. A typical E+ installation scenario is a group of LTE medium range base station integrated on top of a lamppost in an outdoor urban area [SCF2017]. The E+ installations have more stringent restrictions in terms of the accessibility of the installed small cell(s), as illustrated in Figure 37b.



Installation class	E0	E2	E10	E100	E+
Total EIRP	N/A	≤ 2 W	≤ 10 W	≤ 100 W	No limit
Minimum height above walkway	None	None	2.2 m	2.5 m	H_m (calculation)
Exclusion zone	None, touch compliant	Provided in manufacturer's instructions Small D_m not shown on the picture		Provided in manufacturer's instructions D_m in main lobe direction	
Check pre-existing RF sources	N/A	N/A	N/A	$5D_m$ in main lobe direction D_m in other directions	

Figure 36 SCF and GSMA recommended simplifications in the small cell installation rules [SCF2017]

(a) **(b)**

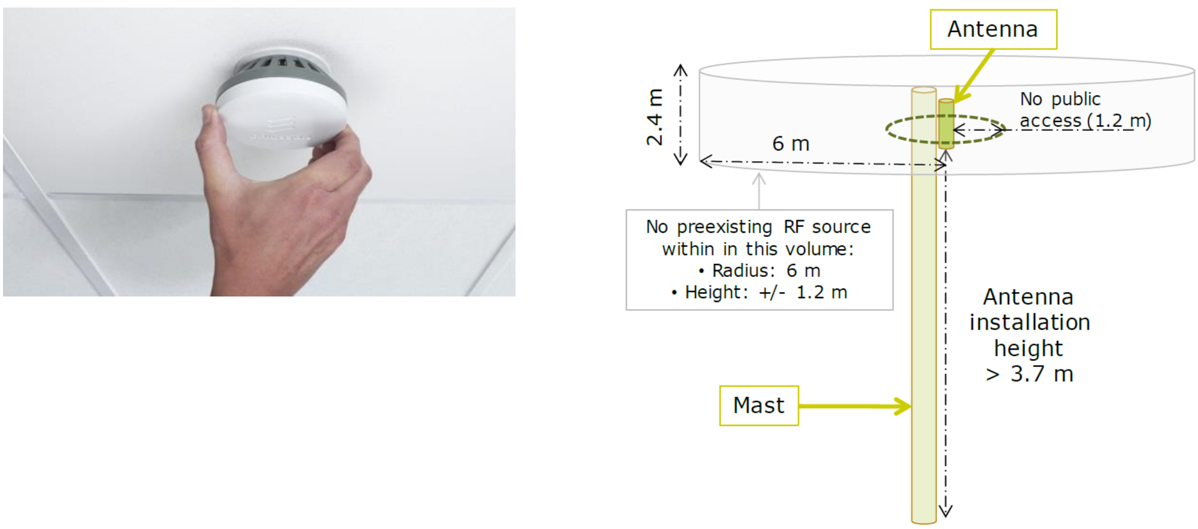


Figure 37 Example small cell installations for class E0 (Ericsson Radio Dot)[34] and class E+ [SFC2017]

4.2.4 *Approvals, licensing and permits for small cell deployments*

The fact that the number of small cell deployments will far exceed those of macro deployments (by at least one order of magnitude), the **small cell deployment processes** have to be **relatively cheaper, simpler and faster** compared to traditional macro site deployment processes. The SCF has illustrated the typical workflow in designing, planning, building and operating small cells (see Figure 38). This includes the following steps [SCF2014b]:

[34] https://www.ericsson.com/assets/local/narratives/networks/documents/radio-dot-system-brochure.pdf

- *Business model phase*: This phase involves the appropriate business or commercial model considering factors including the deployment scenario (e.g. public enterprise, residential, urban outdoor etc.) and ownership of the small cell infrastructure (e.g. MNO small cells, neutral host small cells etc.). The example models include MNO site share, neutral host leased (wholesale) capacity, MNO self-deployed (unshared) and enterprise purchase model.

- *Design and planning phase*: This phase is includes the various network design and planning activities (RF coverage planning, RAN and backhaul capacity dimensioning, capability analysis, etc.). This phase provides the guidelines for the subsequent network building and operational phase, as well as, assessing any potential regulatory impacts.

- *Building phase*: This phase is where the small cell physical equipment is installed, commissioned and undergo acceptance physical equipment installation, small cell commissioning, and acceptance processes (e.g. test procedures and performance valuation to very compliance with SLAs) before the network becomes operational.

- *Operational phase*: This phase encompasses the central operations, monitoring, maintenance, and performance assurance to ensure that small cell installations maintain their coverage and capacity performance as indicated in the design and planning phase.

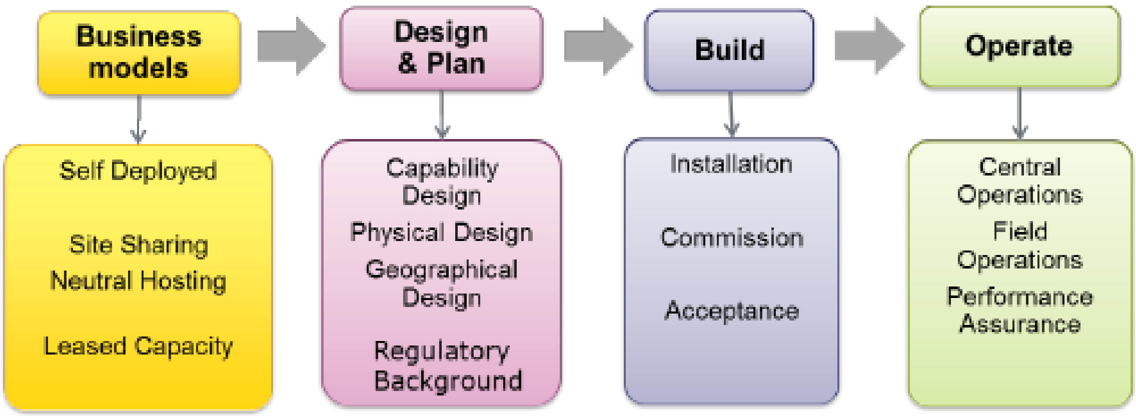


Figure 38 Small cell deployment framework [SCF2014b]

The small cell deployment processes involves a number of diverse stakeholders. This includes supply-side stakeholders (e.g. vendors, MNOs, neutral hosts, system integrators etc.) who provide the equipment and engineering expertise needed during design, planning and operational phases. The other key stakeholders are the governance stakeholders (NRAs and local governments) who provide equipment approvals, building permits, operating licenses and impose relevant fees or taxes on small cell operators. The deployment processes that depend on governance stakeholders are usually beyond the direct influence of the supply-side stakeholders and usually present some of the most significant challenges for the overall deployment processes.

4.2.4.1 Product approval

The small cell products need to get approval prior to the design and planning phase. These approvals may include, for instance, certification of product compliance to RF EMF exposure limits as described in Section 4.2.3. The differences in approval or exemption criteria across different countries creates fragmentation for MNOs seeking approval which complicates and delays the subsequent deployment processes, and limits the scalability required for dense small cell deployments [SCF2016]. Therefore, equipment approvals are preferably provided by NRAs at a national or regional (e.g. EU region) level using generic declarations and standardised equipment classes (e.g. IEC 62232 Ed.2.0 installation classes described in Section 4.2.3) that ease the small cell product approval burden for both the applicants and the administrators.

4.2.4.2 Spectrum licensing

Similarly, the RF spectrum licensing by NRAs may vary across different countries as noted briefly in Section 4.2.2 and in described more detail in the SMART 2016/0019 report [EC2017b]. This is out of line with the Digital Single Market (DSM) strategy of Europe with seeks harmonisation of rules, regulations and policies to facilitate a single market for telecommunications [EC2015]. Harmonisation usually exists for band selection for technologies (e.g. 5G pioneer bands) and services (e.g. 5.9 GHz ITS band).

However, there are significant country-to-country variations in terms of the type of authorisation (e.g. individual right of use, general authorization, etc.), license awarding mechanisms (e.g. auction, administrative selection, first-come first-served etc.), and licensing conditions (e.g. coverage obligations, spectrum sharing, spectrum trading and leasing restrictions, etc.). This fragmentation creates challenges in ensuring timely availability of spectrum for deployment of small cells in different scenarios (outdoor, private indoor, public indoor etc.) and across different countries. This is particularly critical for multinational MNOs deploying and operating small cell networks in multiple countries (multi-territorial or pan-European scale).

To that end, the draft EECC directive (Articles 48-54 [EC2017]) is proposes greater coordination and harmonisation of the rules for spectrum management within the EU. This includes laying down general rules on aspects such as spectrum use, taxation, time scales, license duration and transparency of NRAs' processes on spectrum allocation and re-allocation of spectrum.

4.2.4.3 Planning permissions

Site identification and planning (building or siting) permissions are considered by MNOs to be the one of the most significant barriers to dense small cell deployments (see Figure 39). The applications for these planning permits for base station deployment are in most cases handled by the local government authorities (e.g. municipalities) in the target area of deployment. The planning aspects considered in the application may include [GSMA2013, SCF2016]:

- Certification of product compliance to RF EMF exposure limits and product installation compliance.
- Building permits including owner property authorisation and public domain right-of-ways.
- Consideration of environmental, historical or other planning restrictions in areas, such as, schools, hospitals, and so on.
- Taxes and fees applicable at national and/or local level. These include administrative fees for processing the planning application, equipment installation taxes, and single or recurring operational fees.

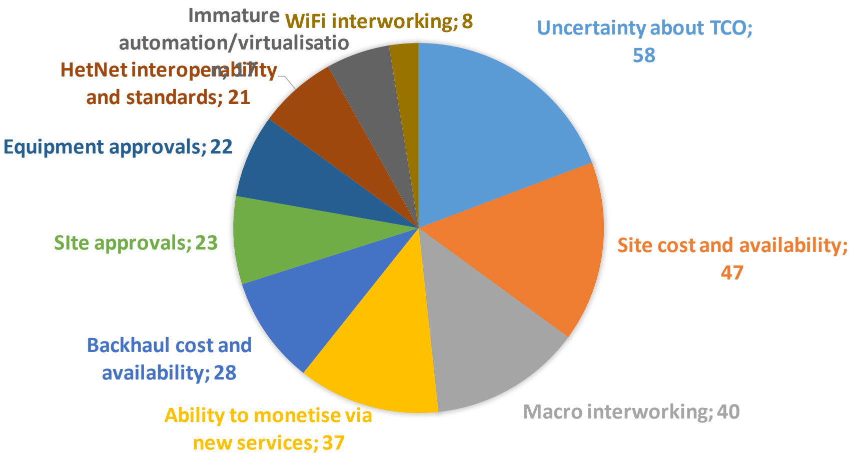


Figure 39 Results of operator survey on barriers to small cell deployment (78 operators selected their top three barriers. Source: Rethink Research, SCF)

The confluence of the different planning aspects considered above, would usually result in costly and lengthy planning application processes. A past survey by GSMA on the planning processing times in different countries noted an average processing time of one year (see Figure 40) [GSMA2016]. In the case of small cell deployments, the complexity of the process for obtaining planning permissions is further exacerbated by [SCF2016]:

- The administrative effort and time required to handle a large number of planning applications for increasingly dense small cell deployments.
- The likely need to apply for planning permissions for deploying backhaul (or fronthaul) connectivity to a larger number of small cell sites. In case of wireline backhaul, there is need to obtain rights-of-way for laying cables to small cell sites, whereas, wireless LOS/nLOS backhauling at high frequencies may require planning permissions due to ensure compliance to RF EMF exposure limits.
- The fragmentation in the planning application processes, due to variations in procedures (e.g. format of forms, planning fees, processing times etc.) from one local authority to another, due to differing local situations or peculiarities.

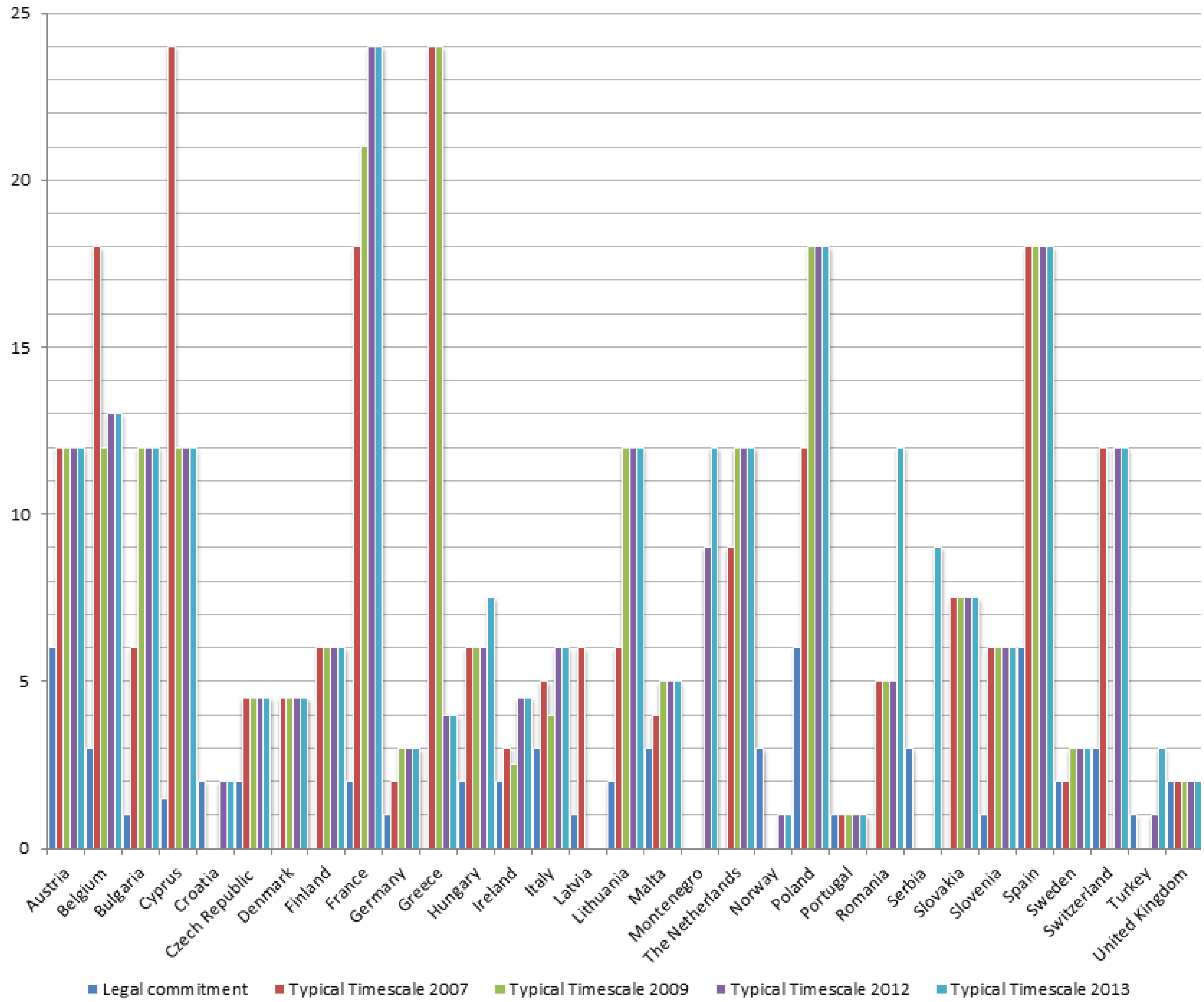


Figure 40 Comparison between legal requirements and typical timescales (in months) for granting permission for Base Station deployment in different countries [GSMA2013]

The planning application times indicated would make the dense deployment of small cells challenge and impact rollout of 5G in currently envisioned timelines. Therefore, a number of recommendations have been proposed (notably by SCF and GSMA) and are in some cases already adopted by some countries to accelerate and simplify the planning permissions for small cells. These include:

- Use of generic permits or exemptions based on internationally standardised equipment classes (e.g. IEC 62232 Ed.2.0 installation classes).
- Harmonisation of the rules and administrative processes for planning permissions across different authority domains in accordance with the DSM strategy for Europe [EC2015].
- Simplified administrative processes for small cell deployments through use 'one stop shop' application procedures, reducing the decision-making chain and necessary paper work.
- Proving tacit approval if local authorities do not oppose an authorisation request within a certain number of days or weeks.
- Maintaining a database of qualified candidate site locations to speedup site identification and further simplify processing of applications.

- Incentivising small cell deployments through revision or full exemptions (for small cells) of the base station taxes and recurring fees originally devised for macro base stations.

5 Exemplary Country Case Studies

5.1 Background

Exemplary case studies (as noted in Section 1.3.3) are useful in providing anecdotal evidence on some of the barriers to dense small cell deployments (particularly challenges that are not unique to a particular market) and the different approaches taken overcome these barriers. To that end, different four case study countries were selected;

- Two countries (United Kingdom and Netherlands) from the EU region;
- Two countries (USA and India) from the North America and APAC regions, which are projected to have the largest volume of small cell deployments up to 2025 (as noted Section 2.2.3).

As a background, each case study is preceded by a contextual description of each country. This description is provided in the form of tabulated country profiles that include the following information:

- *Population statistics*: Current and future projects of national and urban populations are presented to provide contextualisation the level of urbanisation and likely demand for dense small cell deployments in urban areas.
- *Mobile market data*: This data provides indicators on demand-side and supply-side aspects of the mobile market. This includes:
    - Level of adoption of mobile broadband services;
    - Affordability of mobile broadband access represented in terms of price of 1 GB of data as a percent of Gross National Income (GNI) per capita[35];
    - The level of network rollout in terms of the percentage of population within the coverage area of LTE networks); and
    - The mobile market structure, indicating main operators and their respective market share.
- *Regulatory and policy info*: This includes mention of some key policy developments and main governance stakeholders (NRAs and local government authorities).

[35] GNI per capita is the gross national income divided by mid-year population. GNI per capita in US dollars is converted using the World Bank Atlas method.

5.2 United Kingdom

5.2.1 UK contextual background

Table 21 United Kingdom country profile[36]

	United Kingdom 
Population [value (year)]	63.3 million (2014) 73.1 million (2050)
Proportion of urban population [% (year)]	82% (2015) 89% (2050)
Area	242,495 km²
Active mobile-broadband subscribers per 100 inhabitants [value (year)]	80.1 (2016)
Mobile-broadband prices 1 GB [% GNI per capita (year)]	0.6% (2016)
LTE coverage [% of population (year)]	98.5% (2016)
Main mobile network operators (% market share, 2017)	EE (35%), O2 (20%), Vodafone (21%), Three (14%)
Notable governance stakeholders	• *NRA*: Office of Communications (Ofcom)[37] • *Local administration*: 34 counties. Counties sub-divided into 269 local districts and boroughs. Local authorities in England develop local broadband plans, and develop and manage projects to support superfast broadband rollout in areas not served by commercial coverage. Department of the Economy, Scottish and Welsh governments responsible for management of broadband rollout in Northern Ireland, Scotland and Wales, respectively. • The Government Department for Culture, Media and Sport (DCMS)[38] is responsible for broadband policy. • Broadband Delivery UK (BDUK)[39] is part of DCMS and is the delivery vehicle for the Government's broadband policies relating to stimulating private sector investment and using available funding across the UK.
Key policy developments	• Liberalization of its telecommunication sector from 1984, when the government sold its majority shares in operator BT. • In December 2017, Government has confirmed that universal high speed broadband will be delivered by a regulatory *Universal Service Obligation (USO)*[40], giving everyone in the UK access to speeds of at least 10 Mbps by 2020.

[36] Data sources include UN [UN2014], ITU [ITU-D2017], Radiocells.org (https://www.radiocells.org/) and EC DSM page https://ec.europa.eu/digital-single-market/en/country-information-united-kingdom
[37] https://www.ofcom.org.uk/
[38] https://www.gov.uk/government/organisations/department-for-culture-media-sport
[39] https://www.gov.uk/guidance/broadband-delivery-uk
[40] https://www.gov.uk/government/news/high-speed-broadband-to-become-a-legal-right

5.2.2 UK Case study description

5.2.2.1 Challenges in dense deployment of small cells

The UK is a highly urbanised country with a great demand densify networks, particularly in the urban areas to meet the Universal Service Obligation (USO) targets. The deployment of mobile base stations requires approval from local counties, district and borough authorities, as well as, consultations with local communities in some cases. This presents significant challenges to MNOs in terms of securing planning permits for nationwide rollouts.

5.2.2.2 Description of intervention to facilitate dense small cell deployments

Mobile UK, the trade association for the UK's mobile network operators (EE, O2, Three and Vodafone) participated in development of the *Code of Best Practice on Mobile Network Development in England* (The Code) [MobileUK2016], in collaboration with a number of government and various public advocacy stakeholders, including:

- The Department for Communities and Local Government;
- The Department for Culture Media and Sport;
- The Department for Environment, Food and Rural Affairs;
- Historic England;
- The Local Government Association;
- Landscapes for Life;
- National Parks England; and
- The Planning Officers Society.

This Code of Best Practice provides clear and practical advice to ensure the delivery of significantly better and more effective communication and consultation between MNOs, local authorities and local communities impacted by mobile base station deployments in England. The principal aim of the Code is to ensure that the deployment of mobile infrastructure needed to meet USO targets is carried out in a timely and efficient manner, and in a way, which balances connectivity imperatives and the economic, community and social benefits that this brings with the environmental considerations that can be associated with such deployments.

The Code is derived from the principles set out in Section 5 of the National Planning Policy Framework (NPPF)[41], which state that:

- The development of high-speed broadband technology and other communications networks plays a vital role in enhancing the provision of local community facilities and services.

- The numbers of radio and telecommunications masts and sites for such installations should be kept to a minimum consistent with the efficient operation of the network.

- Existing masts, buildings or other structures should be used unless the need for a new site has been justified; and

- Where new sites are required, equipment should be sympathetically designed and camouflaged where appropriate.

The Code provides standardised practice that promotes greater consistency of approach and aid the transparency of the process of mobile network planning permits for all concerned. Furthermore, the Code provides advice on good siting and design of mobile base stations to direct deployments to the most appropriate locations, as well as, help to minimise environmental impact and visual intrusion. The Code applies to all forms of wireless deployment, but is particularly relevant to proposals for new masts or base stations and significant additions, extensions or replacements of existing mobile base

[41] https://www.gov.uk/government/publications/national-planning-policy-framework--2

station sites. A separate code applies to fixed line operators.

The Code notes the following roles and responsibilities for the key stakeholders in the application process for planning permissions:

- *Central Government*: has a role in setting the overall strategy for connectivity, and in framing appropriate policy and regulation (including health policies related to any potential health issues from human exposure to RF EMF).
- *Local planning authorities*: have a vital role in facilitating network development through the operation of the planning system and, for example, in helping to identify land and structures suitable for mobile infrastructure. Local planning authorities can also ensure that the planning function works in tandem with other relevant departments and agencies such as their own economic development departments and appropriate digital connectivity teams in order to facilitate digital connectivity.
- *Mobile operators*: responsibility to deliver the mobile network infrastructure, and to do so in a responsible manner, but also considering economic factors. This includes MNO commitments to site sharing; consultation with local planning authorities, local communities and other stakeholders; standardised supporting documentation for planning applications; implementing workshops for local planning authorities; and ensure compliance with ICNIRP RF EMF exposure guidelines.

The Code also makes special mention of "small scale equipment" (small cells). The Code states that deployment of small cells involves "*some minor operations or works and may not constitute development which requires planning permission*." The Code likens small cells to other small antennas systems (e.g. television aerials) which are covered by the normal *principle de minimis*, and proposes small cells are treated in the same way (regardless of who install them) and each case should be treated on its merits. However, the Code recommends that small cell deployments should be concealed using measures, such as, installing them in areas that inconspicuous, minimising equipment and clutter, avoiding contrast with or compromising architectural detail, concealing cable runs or exploiting architectural detail to minimise their visual impact.

5.3 Netherlands

5.3.1 Netherlands contextual background

Table 22 Netherlands country profile[42]

	Netherlands 
Population [value (year)]	16.7 million (2014) 16.9 million (2050)
Proportion of urban population [% (year)]	90% (2015) 96% (2050)
Area	41,850 km^2
Active mobile-broadband subscribers per 100 inhabitants [value (year)]	88.9 (2016)
Mobile-broadband prices 1 GB [% GNI per capita (year)]	0.5% (2016)
LTE coverage [% of population (year)]	99% (2016)
Main mobile network operators (% market share, 2017)	KPN (35%), Vodafone (33%), T-Mobile (25%), Tele2 (7%)
Notable governance stakeholders	• *NRA*: Ministry of Economic Affairs (Ministerie van Economische Zaken)[43] • *Local administration*: 32 biggest municipalities (cities) of the Netherlands are organised in the special network organisation "StedenLink" that promotes the optimum usage of ICT along with the local and regional interests and needs.
Key policy developments	• An open and high-speed infrastructure is one of the five lines of action identified in the *Digital Agenda for the Netherlands*[44], the national broadband strategy. • The 2011-2015 Agenda was mostly focused on the digitization of the government itself. Current agenda takes a more comprehensive approach and aims to achieve the digitization of sectors such as healthcare and mobility. • The Digital Agenda for the Netherlands supports a technology neutral approach and sets the target of 100% coverage of 30 Mbps and 50% household penetration of 100 Mbps by 2020. • The strategy also emphasizes the role of local and regional actors in coordinating infrastructure rollout and facilitating the exchange of information.

[42] Data sources include UN [UN2014], ITU [ITU-D2017] and EC DSM page https://ec.europa.eu/digital-single-market/en/news/digital-single-market-strategy-europe-com2015-192-final
[43] https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken-en-klimaat
[44] https://www.rijksoverheid.nl/onderwerpen/ict/inhoud/ict-en-economie/nederlandse-digitale-agenda

5.3.2 Netherland case study description

5.3.2.1 Challenges in dense deployment of small cells

The city of Amsterdam is the financial and cultural capital of Netherlands. Almost one-in-ten of the inhabitants of Netherland reside in the urban Amsterdam area. As in all major European city, there is a need to densify the mobile networks of the city to accommodate the increasing traffic volumes and provide a broadband connectivity platform for initiatives, such as, Amsterdam Smart City[45]. At the same time, the city strives to become one of the "greenest," most sustainable cities in Europe while continuing to attract businesses and maintain economic growth. Amsterdam is one of the oldest continuously inhabited European cities, renowned architectural heritage and some historical attractions (e.g. the 17th-century canals of Amsterdam) included on the UNESCO World Heritage List. Therefore, network densification projects in Amsterdam should take particular care of city's architectural, environmental and historical considerations.

5.3.2.2 Description of intervention to facilitate dense small cell deployments

In the year 2014, Vodafone (one of the top two MNOs in Netherlands by market share), embarked on a pilot project to deploy 200 small cells in Amsterdam. For this project, Vodafone collaborated with JCDecaux[46], the global leading company for outdoor advertisements. JCDecaux has over 100,000 street furniture assets across the markets that Vodafone operates, including Netherlands. In these locations, JCDecaux would already have existing agreements with the local authorities, with typical contracts of 10-20 years already in place. By leveraging these existing permits, Vodafone and other operators are able to significantly speed up their small cell rollouts. For the pilot project JCDecaux leveraged bus shelters and roadside advertising panels (which it uses to deploy adverts) as sites for concealed installation of the Vodafone small cells (see Figure 41).

Figure 41 Small cell equipment concealment in bus shelters and roadside advertising panels [Merlin2017]

The street furniture used by JCDecaux also includes facilities for powering the small cells and terminating fibers that were laid on the street (see Figure 42), thus eliminating or reducing the need to additional civil works and providing future-proofed high-speed backhauling[47] capable of supporting upgrades to 5G. The small cell project provided some other significant benefits, including:

[45] https://amsterdamsmartcity.com/
[46] http://www.jcdecaux.com/press-releases/jcdecaux-and-vodafone-sign-global-contract-roll-out-small-cells
[47] The is particularly useful as JCDecaux observed that fiber is needed for 95% of sites because of poor line-of-sight options for high capacity millimeter wave backhaul. https://www.thinksmallcell.com/Events/das-and-small-

- Demonstrating capability to rollout 200 small cell sites within 12 months (compared to 18-24 months needed to deploy single macro base station in same area);
- Producing site designs that limit RF-EMF exposure to 2 V/m;
- Enabling multi-operator passive sharing[48] by accommodating up to four separate small cells within the same street furniture asset.
- Minimising visual impact to the point of the sites not being noticeable to the local population.

The success of the project led to JCDecaux signing a global 15-year contract[49] with Vodafone to deploy small cells on its street furniture assets.

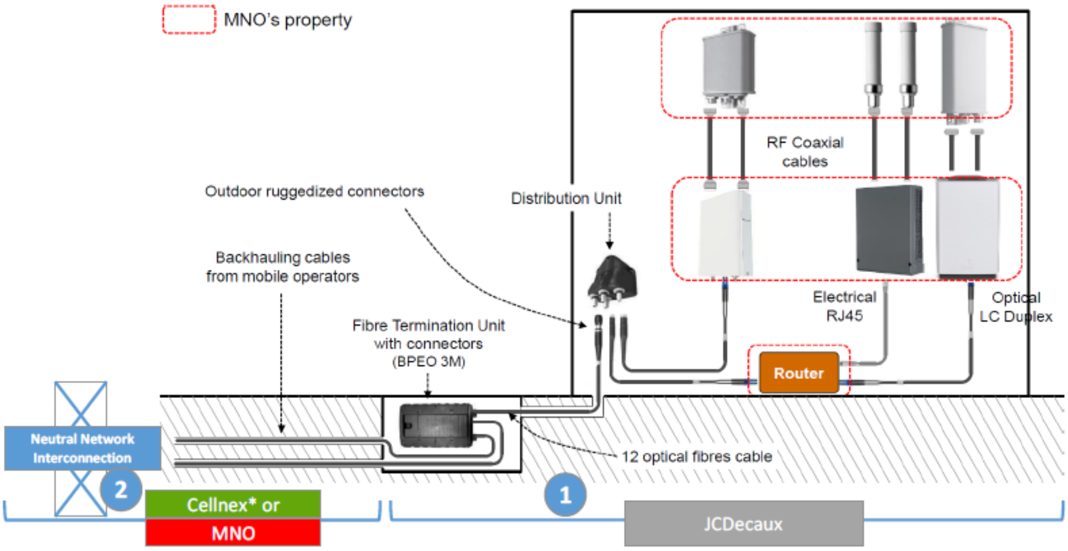


Figure 42 Typical equipment configuration at a site utilising JCDecaux street furniture [Merlin2017]

cells-congress-event-report-november-2017.html
48 https://www.thinksmallcell.com/Urban/jcdecaux-offers-multi-operator-urban-small-cell-solution.html
49 http://www.jcdecaux.com/press-releases/jcdecaux-and-vodafone-sign-global-contract-roll-out-small-cells

5.4 United States

5.4.1 US contextual background

Table 23 USA country profile[50]

	USA 
Population [value (year)]	322.5 million (2014) 400.8 million (2050)
Proportion of urban population [% (year)]	81% (2015) 87% (2050)
Area	9,525,067 km^2
Active mobile-broadband subscribers per 100 inhabitants [value (year)]	124.9 (2016)
Mobile-broadband prices 1 GB [% GNI per capita (year)]	0.3% (2016)
LTE coverage [% of population (year)]	99.7% (2016)
Main mobile network operators (% market share, 2017)	Verizon (36%), AT&T (33%), T-Mobile (17%), Sprint (13%), US Cellular (1%)
Notable governance stakeholders	• *NRA*: The Federal Communications Commission (FCC)[51] • *Local administration*: 50+2 States (including District of Columbus and Puerto Rico). States regulate matters, such as setting and monitoring of quality of service standards. States sub-divided into 3,144 counties (which include 137 county equivalents). The government of the county usually resides in a municipality called the county seat.
Key policy developments	• FCC unveiled *Connecting America: The National Broadband Plan*[52] in 2009 with targets including providing 100 million American households with access to 100 Mbps connections by 2020. • Latest FCC guidelines, the *Strategic Plan 2015–2018*[53], outlines the importance of public interest goals such as consumer rights, safety and access to broadband, while ensuring that economic growth and security remain high priorities. • Current FCC initiatives[54] include Restoring Internet Freedom, Bridging the Digital Divide, Forging our 5G Future. Broadcast Incentive Auction, Connect2HealthFCC, Accessible Communications for Everyone.

[50] Data sources include UN [UN2014], ITU [ITU-D2017] and FCC
[51] https://www.fcc.gov/
[52] http://www.broadband.gov/plan/executive-summary/
[53] https://apps.fcc.gov/edocs_public/attachmatch/DOC-331866A1.pdf
[54] https://www.fcc.gov/about-fcc/fcc-initiatives

5.4.2 US case study description

5.4.2.1 Challenges in dense deployment of small cells

The USA has been one of the leading countries in terms of small cell deployments, with number of mobile sites in service exceeding 300,000 by end of 2016 (see Figure 43), with a significant fraction of those being small cell sites. However, further denser deployments are needed[55] to expand the capacity of existing LTE networks and lay the foundations for future 5G upgrades [FCC2016]. To that end, the utility poles represent ideal street furniture for dense deployment of small cells. It has been noted that there were 120 million utility poles in service in the United States in 2005, with an overwhelming majority of them having a service life of 75 years or more [2016].

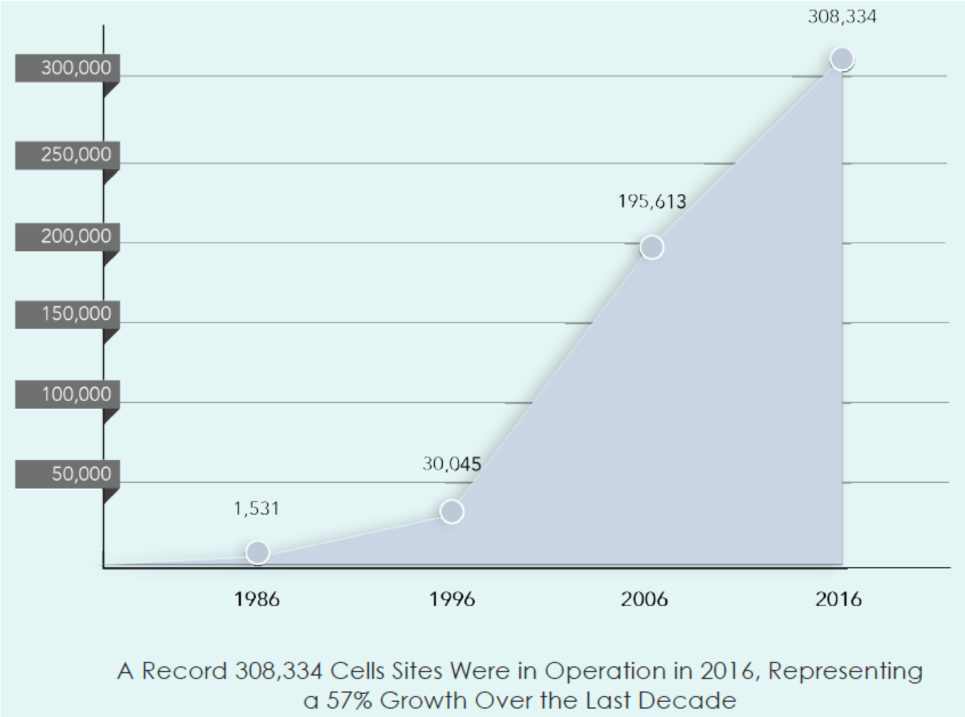


Figure 43 Number cell sites in service in USA up to year 2016 [CTIA2016b]

FCC have formulated various regulations to ensure MNOs have access sites to facilitate simplified and rapid deployment of cell sites, including utility poles. This is explicitly stated in Federal law (Section 224 of the Communications Act), which obliges utilities to afford MNOs and cable operators non-discriminatory access to poles, ducts and conduits under "just and reasonable" rates, terms and conditions [FCC2015]. However, access to utilities poles has been complicated by some states (Reverse Pre-emption States) adopting their own rules for attaching small cells to poles (see Figure 44). These local rules in many cases has led to excess administration fees and pole attachment fees well above those permitted by FCC rules, as well as, long delays in processing of pole attachment agreements [CTIA2016].

55 https://www.rcrwireless.com/20151029/carriers/can-verizon-and-att-deploy-100000-new-small-cells-tag4

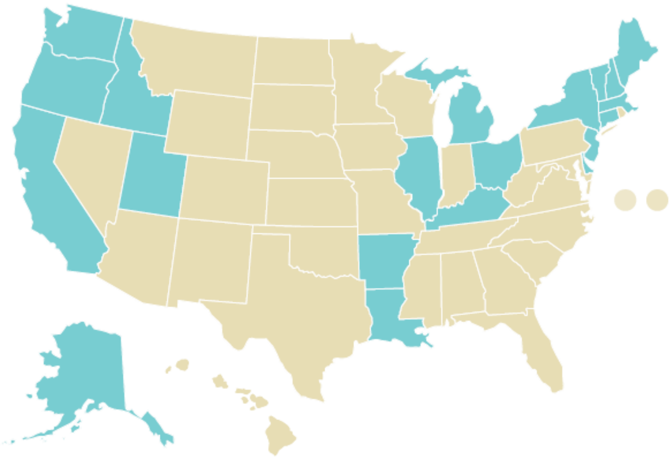


Figure 44 States above in blue have own regulations for pole attachments [CTIA2016]

5.4.2.2 Description of intervention to facilitate dense small cell deployments

In January 2017, the FCC Chairman announced the formation of the Broadband Deployment Advisory Committee (BDAC)[56]. The main aim of BDAC is to make recommendations for FCC on how to accelerate the deployment of high-speed Internet access, by reducing and/or removing regulatory barriers to infrastructure investment. To that end, BDAC intends to provide an effective means for stakeholders with interests in this area to exchange ideas and develop recommendations for the FCC, which will in turn enhance FCC's ability to carry out its statutory responsibility to encourage broadband deployment to all inhabitants. BDAC has been established for an initial period of two years, starting from spring 2017. Within the year 2017, the committee managed produce a set of draft recommendations which were eventually approved after a vote in November 2017 (see timeline of Figure 45). The resulting recommendations approved by BDAC are shown in Figure 46.

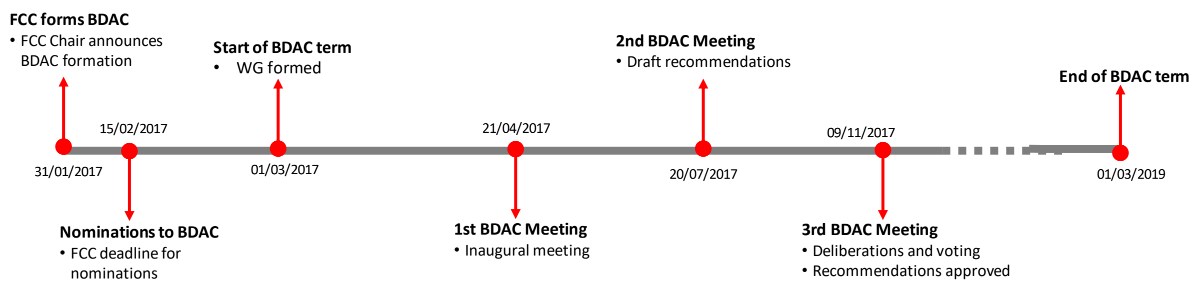


Figure 45 BDAC timeline

56 https://www.fcc.gov/broadband-deployment-advisory-committee

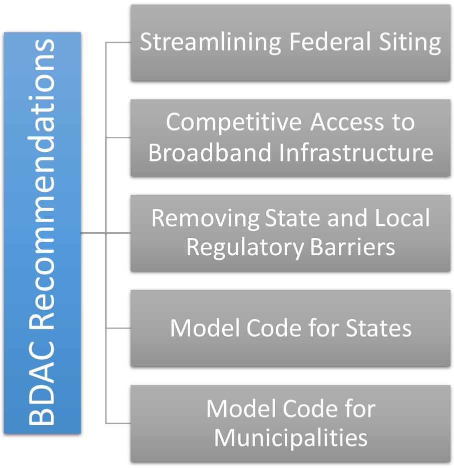


Figure 46 Recommendations approved by BDAC

The recommendation on "*Competitive Access to Broadband Infrastructure*"[57] specifically addressed the challenges of pole attachment agreements described in Section 5.4.2.1. In particular, the recommendations put forward proposals on three key issues commonly encountered in this process:

Issue 1: Pole attachers (entities deploying small cells on utility poles) and pole owners have expressed concern about the *length of time taken in certain circumstances to resolve pole attachment complaints*, which produces uncertainty that might impact deployment of broadband facilities. For this issue the BDAC proposals were as follows:

- *Except in extraordinary circumstances, final action on a complaint filed by a cable television system operator or telecommunications carrier regarding claims involving access to a pole, duct, conduit or right-of-way owned or controlled by a utility should be expected no later than 180 days from the date the complaint is filed with the Commission.*
- *The Commission shall have the discretion to pause the 180-day review period in situations where actions outside the Commission's control are responsible for delaying Commission review of an access complaint.*

Issue 2: Pole attachers and pole owners do not have an *expedited process for resolving complaints about rates or fees related to the attachment process*. Such issues can languish for a protracted amount of time at the FCC, which impedes broadband deployment. For this issue the BDAC proposals were as follows:

- *A reasonable shot clock process of 180 days should be applied to complaints filed by pole owners and pole attachers.*

Issue 3: In rare instances, in calculating attachment rates, some pole owners have included capital costs that have been previously recovered in the calculation of make-ready fees. For this issue the BDAC proposals were as follows:

- *Pole owners should not be able to recover capital costs through the make ready process more than once.*

[57] https://www.fcc.gov/sites/default/files/bdac-11-09-2017-competitive-access-to-broadband-infrastructure-approved-rec.pdf

The BDAC recommendations have been very positive in terms of addressing the barriers that have previously impeded small deployments on utilities poles and federal property. However, there has been criticism from other stakeholders; due to the fact that the composition of the BDAC was heavily in favour of the telecom industry (only 2 out of the 30 members came from a non-telecom organisation)[58]. Similar concerns have been raised by the National Association of Regulatory Utility Commissioners (NARUC)[59], which produced the following statement to FCC prior to the BDAC recommendations [NARUC2017]:

> " *… It is self-evident, that any recommendations will necessarily reflect the composition of the committee. A simple review of the current roster suggests the committee is heavily weighted in favour of those seeking attachments to poles. The concept for this committee was a good one, but the usefulness of any recommendations is likely to be undermined by this imbalance*."

At the time of writing, there was no additional info on the clarifications provided in response to the concerns raised above.

[58] https://www.thedailybeast.com/almost-all-of-fccs-new-advisory-panel-works-for-telecoms

[59] Founded in 1889, the National Association of Regulatory Utility Commissioners (NARUC) is a non-profit organization dedicated to representing the State public service commissions who regulate the utilities that provide essential services such as energy, telecommunications, power, water, and transportation. https://www.naruc.org/

5.5 India

5.5.1 India contextual background

Table 24 India country profile[60]

	India 
Population [value (year)]	1267.4 million (2014) 1620.1 million (2050)
Proportion of urban population [% (year)]	32% (2015) 50% (2050)
Area	3,287,263 km^2
Active mobile-broadband subscribers per 100 inhabitants [value (year)]	16.8 (2016)
Mobile-broadband prices 1 GB [% GNI per capita (year)]	3.8% (2016)
LTE coverage [% of population (year)]	73.5% (2016)
Main mobile network operators (% market share, 2017)	Bharti Airtel (25%), Vodafone (18.4%), IDEA Cellular (17%), Jio (13%), BSNL (9.4%), Aircel (7.8%), Rcom (5.4%), Tata Docomo (3.6%), MTNL (0.3%)
Notable governance stakeholders	• *NRA*: The Telecom Regulatory Authority of India (TRAI)[61] • *Local administration*: 29 states and 7 union territories. States and territories (or divisions) are further subdivided into districts (zilla), of which there are 696 (as of 2016).
Key policy developments	• TRAI was established in 1997 to regulate the sector. • The relevant legislation remains the *Indian Telegraph Act of 1885*[62], which has been amended many times. • Policymaking split between the Ministry of Electronics and Information Technology, covering matters related to the Internet other than licensing, and the Ministry of Communications, which is responsible for telecommunications. • The *2012 National Telecommunications Policy*[63] was instrumental in introducing nationwide licences. Policy targets include enabling mobile penetration of 100 per cent in rural areas by 2020, recognition of broadband as a basic necessity, and download speeds of 2 Mbps by 2020 including the availability of 100 Mbps thereafter. • *Digital India*[64] is a flagship government programme with a vision to transform India into a digitally empowered society and knowledge economy. It is an umbrella initiative covering a number of government agencies and departments and centred

[60] Data sources include UN [UN2014], ITU [ITU-D2017], and TRAI

[61] http://www.trai.gov.in/

[62] http://www.dot.gov.in/indian-telegraph-act-1885

[63] http://www.dot.gov.in/relatedlinks/national-telecom-policy-2012

[64] http://www.digitalindia.gov.in/

	on three key areas: digital infrastructure as a utility for every citizen; governance and services on demand; and digital empowerment of citizens.

5.5.2 *India case study description*

5.5.2.1 Challenges in dense deployment of small cells

India has one of the fastest urbanisation rates[65] and cities that rank amongst the highest globally in both in terms of population growth and density (see Figure 47) [KPMG2016, UN2014]. Moreover, the rapidly growing economy and scarcity of legacy fixed line infrastructure, has led to a significant increase in mobile broadband services as large segments of the population come online. From a mobile network design perspective, these factors make network densification essential to fulfil the capacity demands created by the exploding traffic volumes. The MNOs and tower companies in India have aggressively deployed mobile base station sites, with quoted figures putting the number of tower sites at over 400,000 [TAIPA2017]. In this network expansion, small cells and Wi-Fi access points play a key role, with some analysts estimating that, by 2020 over 44% of the macro data traffic in India will be offloaded to small cell and Wi-Fi networks. This has driven MNOs and traditional tower companies to ramp up small cell deployments in India[66].

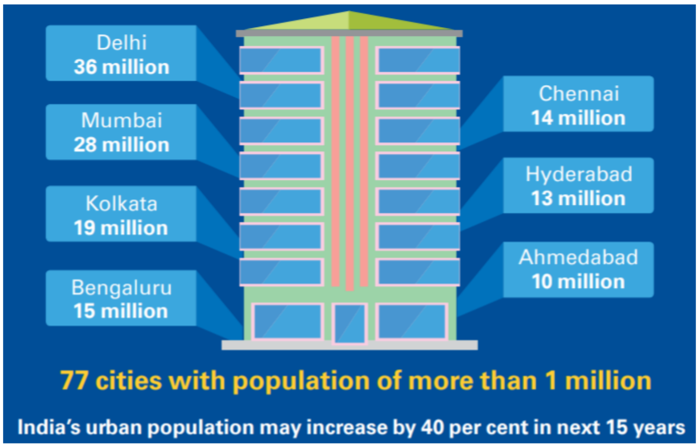


Figure 47 India's largest urban agglomeration by year 2030 [KPMG2016]

The growth of Indian cities is also resulting in a construction boom to cater for infrastructure shortages, such as, housing, office space and public buildings (e.g. shopping centres, transportation hubs etc.). According to analyst projections, India will have the largest construction market globally by 2030 [KPMG2030]. With most of the erected buildings being multi-storey or high-rise buildings, there is a need to also densify small cell deployments in vertical direction to compensate for poor indoor coverage from outdoor macro sites and provide capacity needed for traffic generated in indoor areas.

A number of MNOs have embarked projects to deploy in-building small cells as shown in Jio examples of Figure 48 and Figure 49. However, the indoor densification rate has been slowed-down by a number of factors, such as [TRAI2017]:

- Building owners adopt restrictive practices in giving operators access to in-buildings small

[65] Analysts note every sixth person getting urbanised is an India [KPMG2016]
[66] " Reliance Jio's massive small cell deployment to enable smooth transition to 5G: President Mathew Oommen" 27 February 2017, https://telecom.economictimes.indiatimes.com/news/reliance-jios-massive-small-cell-deployment-to-enable-smooth-transition-to-5g-president-mathew-oommen/57378903
"Ericsson bags small cells deal from top Indian telco, expects deployment to pick up," 29 August 2017 https://telecom.economictimes.indiatimes.com/news/ericsson-bags-small-cells-deal-from-top-indian-telco-expects-deployment-to-pick-up/60274682

cells. This includes entering exclusive agreements with some operators to the detriment of fair competition within the building.

- Building owners charge exorbitant fees for operators to gain access for in-building small cell deployments

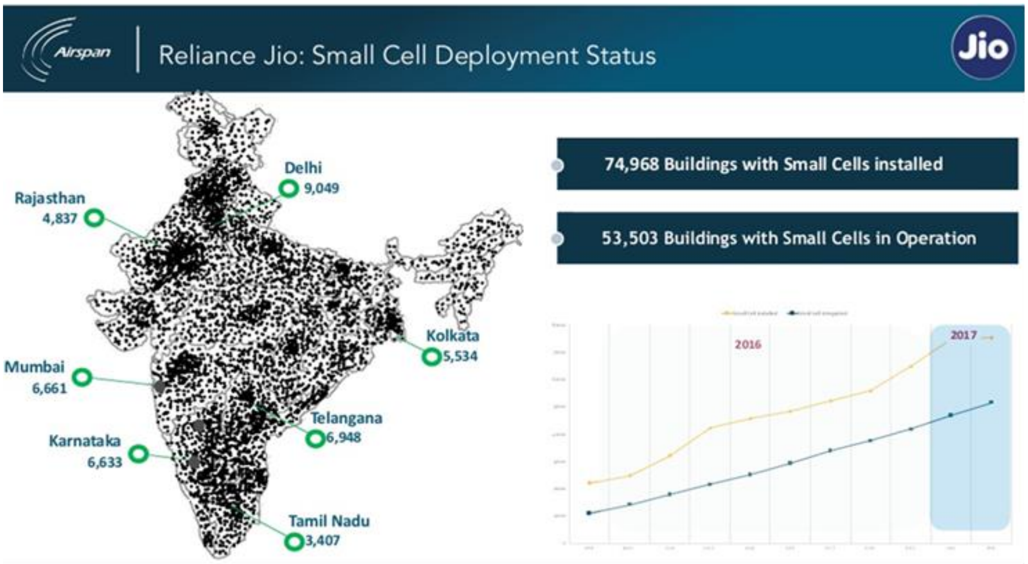


Figure 48 In-building small cell deployments by operator Jio (Source: Airspan)

Figure 49 Example in-building deployment by Jio in Gurgaon, India (Source: Airspan)

5.5.2.2 Description of intervention to facilitate dense small cell deployments

In view of the challenges encountered by operators in in-building small cell deployments, TRAI, the Indian NRA, has produced a series of recommendations that included clauses for overcoming those barriers. These are chronicled in [TRAI2017] and summarised in Table 25.

Table 25 TRAI recommendations of in-building deployments [TRAI2017]

TRAI reference	Date	Recommendations related to in-building deployments
Telecommunications Infrastructure Policy	12 April 2011	• Operators are mandated to share their in-building deployments (Article I.94) • All ministries advised to have in-building deployments (small cells of DAS), within next one year in all Central Government buildings including central Airports and buildings falling under their jurisdiction & control. (Article I.95) • All State Governments should be similarly advised to provide/mandate, within next one year, in-building deployments in all buildings including hospitals having more than 100 beds and shopping malls of more than 25000 square feet super built area. (Article I.96)
Delivering Broadband Quickly: What do we need to do?	17 April 2015	• There is a need to mandate city developers and builders to have properly demarcated sections within buildings and on rooftops for housing broadband infrastructure and antenna. These areas should have uninterrupted power supply for reliable, always-on services" (Article 4.17)

Following the aforementioned recommendations, TRAI issued a consultation Paper on '*In-Building Access by Telecom Service Providers*' on 6 June 2016 seeking comments of the stakeholders (deadline for comments 21 July 2016). This was followed by a public discussion on 30 September 2016. Based on the inputs received from the stakeholders and TRAI's own analysis, the Authority formulated its recommendations on "*Recommendations on In-Building Access by Telecom Service Provider*" [TRAI2017]. The summary these TRAI's recommendations including the following:

i. Operators and neutral hosts should be **mandated to share the in-building infrastructure** (small cells, cable ducts, optical fibres and other cables, etc.) with other operators, in large public places like Airports, hotels, multiplexes, etc.,

ii. Operators and neutral hosts are **prohibited from entering into exclusivity agreements with building owners**. Indulgence into such a practice, through either formal or informal arrangement, may be treated as violation of the license agreement/registration.

iii. A system (time bound) or **shot-clock of 30-days is recommended for handling of requests by operators to access existing in-building infrastructure** of another operator or neutral host

iv. **Commercial terms for sharing of the in-building infrastructure**, may be decided by the in-building infrastructure owner. However, the same shall be done in **transparent, fair and non-discriminatory manner**.

v. Government should ensure that the **essential requirement for telecom installations and the associated cabling is formed part of National Building Code of India (NBC)**

vi. **No building plan should be approved without having a plan for creation of shared in-building infrastructure** including the duct to reach to the telecom room inside the building.

The intervention of TRAI of via these explicit recommendations of Greenfield in-building deployments in new buildings and mandated sharing are likely to create an open and competitive environment in indoor small cell networks. With virtualisation and cloudification becoming a future enhancements to in-building deployments, this will also be an interesting platform for indoor applications and services innovation as noted in Section 2.1.3.

5.6 Cross-case conclusions

The cross-case conclusions formulated from a case study synthesis segmenting the main common theme of the case studies into a number of themes each with its own conclusions [Cruzes2015]. To that end, ***"Interventions to facilitate dense small cell deployments"*** is adopted as the main higher order theme from which five other themes are identified as shown in Figure 50. The definition of the each of themes in the context of the case studies and the respective cross-case conclusions are then provided in Table 26.

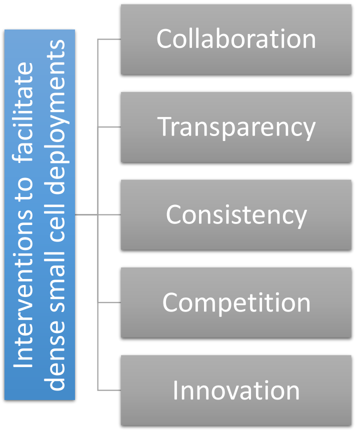


Figure 50 Case study synthesis

Table 26 Cross-case conclusions

Theme	Definition	Conclusion
Collaboration	How different stakeholders are included in intervention processes	Stakeholder inclusiveness is a key perquisite for overcoming most of the barriers against dense small cell deployments. The UK and India case studies demonstrated best practice approaches in including various stakeholders to define procedures for facilitating deployment. Whereas, the USA case study demonstrated the potential challenges that occur when some stakeholders do not feel part of the process definition. The Netherland case study was or good example of the benefits of multi-stakeholder synergies continuing during the building and operational phase.
Transparency	How open are the processes and how is the information exchanged between relevant stakeholders.	Visibility of deployment processes and inter-stakeholder information exchange minimise objections and opens up further opportunities for deployment. The UK provided examples of procedures for timely, clear and unambiguous information exchange between stakeholders, prior to dense small cell deployments.
Consistency	How standardised procedures or rules are defined in the intervention	Consistency (reduced fragmentation), particularly in application for planning permit, is essential to ensure rapidity, predictability and repeatability of dense small cell deployments. The UK case study demonstrated this in greater level of detail, with standardised procedures (format of information and forms) expected for both the applicants and the authorities. Consistency of capital and

Theme	Definition	Conclusion
		operational expenditures (e.g., fees) is also key for business models of applicants. The USA and India case study provided examples on how to tackle this challenge of unsustainable fee rates.
Competition	How principles of free and fair competition have been embedded	Competition in small cell networks will benefit the end consumers and promote innovation. The USA, India and UK case study demonstrated how platform, sites and facilities sharing can formulated and in some cases mandated to ensure competition. The Netherland case study demonstrated how this sharing could be engineered in the field.
Innovation	How new approaches, methods or ideas are adopted in the intervention	The dense small cell deployments requires a departure from legacy (business-as-usual) approaches and methods utilised for macro deployments. The case studies demonstrated innovations, such as, streamlined planning application processes (UK case study); integrated sharing (Netherlands and India case studies); and design for minimising visual impact (Netherland case study).

6 Summary Study Findings and Conclusions

This report has highlighted some of the main regulatory factors that impact dense deployment of small cells. As part of the study presented in this report a stakeholder analysis is carried out to form an understanding of the perspectives of the different stakeholders impacted by dense small cell deployments. The use of case studies has provided additional insights on current barriers in practice and the early efforts by some of the stakeholders in creating an environment that enables rapid and sustainable deployment of small cells. The study findings and conclusions of this report are summarised below along the main regulatory factors considered in this study.

6.1 General definition or classification small cells

The regulatory interventions to facilitate dense small cell deployments require definition or classification of base stations that provide a clear distinction of small cells from conventional macrocells. These definitions or classifications should be standardised and recognised not only across diverse stakeholder groups but also in different countries to facilitate harmonisation of deployment rules and regulations, in accordance with the DSM objectives.

A number of base station classifications have been proposed by different SDOs. The currently consensus seems to be building around the IEC 62232 Ed.2.0 base station installation classes as the preferred classification method, with noted support from industry bodies, such as, SCF and GSMA. The IEC 62232 Ed.2.0 guidelines, utilise EIRP and antenna installation height as the classification criteria, and provide detailed elaboration on technical rationale and evaluation approaches for RF EMF exposure.

The adoption of 62232 Ed.2.0 guidelines in regulatory frameworks could be considered a significant step in formulating regulation that facilitates dense small cell deployments.

6.2 Regulatory implications on sharing of small cells

The requirement for increasingly dense and hyperdense small cell networks (with >150 sites/km^2) makes the sharing small cell infrastructure even more critical than in macrocellular networks. The overlapping dense small cell deployments by multiple operators and neutral hosts is commercially and environmentally unsustainable. The need to encourage or mandate sharing has been highlighted by policy and regulatory initiatives, including the proposed EECC directive.

A factor that has significant impact on the implementation feasibility of the active sharing of small cells is the existence of regulations that permit or even oblige spectrum sharing in particular. Currently there are diverse range of spectrum authorisation and assignments used in different countries. This fragmentation presents challenges for widespread adoption of active sharing of small cells operating in licensed bands. The harmonisation of spectrum sharing regulation and rules targeted by the EECC directive and other initiatives would be a useful step in overcoming this barrier. Moreover, recent specified standards for operation of small cells in unlicensed (license-exempt) bands is yet another development that could remove the spectrum access barrier in small cell sharing.

6.3 RF-EMF exposure limits

The requirement for compliance assessment of small cells in terms of RF-EMF exposure limits is a significant barrier for dense small cell deployments, due to the relatively larger number of small cell sites (both outdoor and indoor) that may need to undergo the costly and time-consuming assessment for product installation compliance.

However, there has been increased recommendations for small cells to have simplified assessments that reduce or eliminate the need for product installation compliance for individual small cell installations. The recommendations are increasingly backed by scientific research results, most of which have concluded that the RF-EMF compliance boundaries typically evaluated based on theoretical maximum transmit powers, create overly conservative EMF limits and may unnecessarily constraint the density of small cell deployments. Furthermore, scientific studies supported by measurements in real deployments could further enhance the validity of these claims.

6.4 Approvals, licensing and permits for small cell deployments

The small cell deployment processes involves a number of diverse stakeholders, which may result in overly complex and prolonged processes for dense small cell deployments. A number of countries have already adopted measures for simplifying planning approval processes for small cells. This includes: the use of generic permits or exemptions based on internationally standardised equipment classes (e.g. IEC 62232 Ed.2.0 installation classes); harmonisation and simplification of the rules and administrative processes for planning permissions across different local authorities; and incentivising small cell deployments through revision or full exemptions (for small cells) of the base station taxes and recurring fees originally devised for macro deployments. Further benefits of the interventions described could be amplified by harmonising some of those procedures across different countries.

The success of Wi-Fi deployments provides an example of what could be achieved through simplifications of approvals, licensing and permits. The fact that Wi-Fi access points and small cells bear many resemblances, such as, their physical and RF characteristics, and deployment scenarios, provides solid argument for adoption of similar simplified rules for small cells (as used for Wi-Fi access points).

7 References

[3GPP2017] 3GPP. "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception" 3GPP TS 36.104, V15.0.0, September 2017 www.3gpp.org/dynareport/36104.htm

[3GPP2017b] 3GPP. "TR 22.886 Study on enhancement of 3GPP Support for 5G V2X Services," 3GPP, March 2017 www.3gpp.org/DynaReport/22886.htm

[5GAmericas2016] 5G Americas. "Network slicing for 5G networks and services" 5G Americas white paper, 2016 http://www.5gamericas.org/files/3214/7975/0104/5G_Americas_Network_Slicing_11.21_Final.pdf

[5GXHaul2015] 5G-XHaul. "D2.1 Requirements Specification and KPIs Document" July 2015

[Aerts2013] S. Aerts et al., "Assessment and comparison of total RF-EMF exposure in femtocell and macrocell base station scenarios" Radiation Protection Dosimetry, Vol. 162, No. 3, pp. 236-243, December 2014

[Aerts2015] S. Aerts et al., "Impact of a small cell on the RF-EMF exposure in a train" Int. J. Environ. Res. Public Health, Vol. 12, pp. 2639-2652, February 2015

[Atreyam2016] S. Atreyam, "Mobile Edge Computing – A Gateway to 5G Era" IDC whitepaper, November 2016 http://carrier.huawei.com/~/media/CNBG/Downloads/track/mec-whitepaper.pdf

[Casad2017] F. Casademunt and J. Sousa. "What you need to know about the rise of small cell infracos" Delta Partner Group, March 2017 https://www.deltapartnersgroup.com/what-you-need-know-about-rise-small-cell-infracos

[CENELEC2008] CENELEC, "Basic Standard on Measurement and Calculation Procedures for Human Exposure to Electric, Magnetic and Electromagnetic Fields (0 Hz–300 GHz)" Standard EN 50413, 2008 http://standards.globalspec.com/std/1642348/cenelec-en-50413

[Collier2016] M. Collier, "Small Cells, Big Opportunities" IDC Insight - DOC #AP40400116, June 2016

[Cooper2006] T. G. Cooper, et al, "Public Exposure to Radio Waves near GSM Microcell and Picocell Base Stations" Journal of Radiological Protection, Vol. 26, No. 2, pp. 199-211, June, 2006.

[Cruzes2015] D. S. Cruzes et al. "Case studies synthesis: a thematic, cross-case, and narrative synthesis worked example" Empirical Software Engineering, Vol. 20, pp. 1634-1665, December 2015.

[CTIA2016] CTIA "Enabling the Wireless Networks of Tomorrow: Rules of the Road for Pole Attachments in States across America" CTIA white paper, April 2016 https://www.ctia.org/docs/default-source/default-document-library/enabling-the-wireless-networks-of-tomorrow.pdf

[CTIA2016b] CTIA "Annual Year-End 2016 Top-Line Survey Results" 2016 https://www.ctia.org/docs/default-source/default-document-library/annual-year-end-2016-top-line-survey-results-final.pdf?sfvrsn=2

[Deloitte2015] Deloitte. "India Tower Industry: The Future is Data" Deloitte report, June 2015. https://www2.deloitte.com/content/dam/Deloitte/in/Documents/technology-media-telecommunications/in-tmt-indian-tower-industry-noexp.pdf

[DSA2017] DSA "DSA Position Paper on Spectrum Provisions of the draft European Electronic Communications Code" Dynamic Spectrum Alliance (DSA) position paper, June 2017. http://dynamicspectrumalliance.org/wp-content/uploads/2017/06/DSA-Position-Paper-on-Spectrum-Provisions-of-the-draft-European-Electronic-Communications-Code.pdf

[EC1999] EC Recommendation 1999/519/EC "on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)" 12 July 1999. https://ec.europa.eu/health//sites/health/files/electromagnetic_fields/docs/emf_rec519_en.pdf

[EC2015] EC. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Digital Single Market Strategy for Europe, Brussels, 6.5.2015, COM(2015) 192." 6 May 2015 https://ec.europa.eu/digital-single-market/en/news/digital-single-market-strategy-europe-com2015-192-final

[EC2016] EC. "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe" Study for the EC by Tech4i2, Real Wireless, CONNECT, Trinity College Dublin and InterDigital, SMART number: 2014/0008, 2016 https://connectcentre.ie/wp-content/uploads/2016/10/EC-Study_5G-in-Europe.pdf

[EC2017] EC. "Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code (Recast) - COM(2016)590" 14 September 2016 https://ec.europa.eu/digital-single-market/en/news/proposed-directive-establishing-european-electronic-communications-code

[EC2017b] EC "Study on Spectrum Assignment in EU" SMART 2016/0019, October 2017 https://publications.europa.eu/en/publication-detail/-/publication/2388b227-a978-11e7-837e-01aa75ed71a1/language-en

[EC2017c] R. Arnold et al., "Implications of the emerging technologies Software-Defined Networking and Network Function Virtualisation on the future Telecommunications Landscape" SMART 2015/0011, Study for EC by Wik Consult, TNO and iDate, 2017 http://www.wik.org/fileadmin/Studien/2017/Foresight_study_SDN.pdf

[Ericsson2017] Ericsson "Ericsson Mobility Report" November 2017 https://www.ericsson.com/en/mobility-report/reports/november-2017

[ETNO2017] ETNO. "ETNO position paper on the European Electronics Communications Code", ETNO position paper, January 2017 https://etno.eu/datas/positions-papers/2017/ETNO%20Position%20Paper%20on%20the%20EECC

[FCC2015] FCC. "Implementation of Section 224 of the Act," Order on Reconsideration, 30 FCC Rcd 13731, 13733, 2015.

[FCC2016] FCC. "Annual Report and Analysis of Competitive Market Conditions with Respect to Mobile Wireless, Eighteenth Report," DA-16-1061A1, September 2016. https://www.fcc.gov/document/19th-mobile-wireless-competition-report

[Fletcher2003] A. Fletcher. "Mapping stakeholder perceptions for a third sector organization" J. Intellect. Cap. Vol. 4, No. 4, pp. 505–527, 2003 http://www.emeraldinsight.com/doi/full/10.1108/14691930310504536

[Frenger2017] P. Frenger, "5G network energy performance" ETSI-ITU joint Workshop Towards Setting Environmental Requirements for 5G, ETSI, Sophia Antipolis, France, 23 November 2017

[Ge2017] X. Ge, J. Yang, H. Gharavi and Y. Sun, "Energy Efficiency Challenges of 5G Small Cell Networks," IEEE Communications Magazine, vol. 55, no. 5, pp. 184-191, May 2017.

[Ghanbari2013] A. Ghanbari, J. Markendahl and A. A. Widaa, "Regulations for and against cooperation in small cells: How could regulations stimulate co-opetition by supporting sharing?" 24th European Regional Conference of the International Telecommunication Society, Florence, Italy, 20–23 October 2013.

[GSMA2013] GSMA. "Base station planning permission in Europe 2013" GSMA report. https://www.gsma.com/publicpolicy/base-station-planning-permission-in-europe

[GSMA2016] GSMA. "Improving wireless connectivity through small cell deployment", GSMA Booklet 2016. https://www.gsma.com/publicpolicy/wp-content/uploads/2016/12/GSMA_Small_Cell_Deployment_Booklet.pdf

[GSMA2016b] GSMA. "GSMA position on the European Electronic Communications Code (COM (2016) 590 final" GSMA position paper, November 2016 https://www.gsma.com/gsmaeurope/wp-content/themes/theme_europe/eu/GSMA-position-on-EEC.pdf

[GSMA2017] GSMA. "5G, the Internet of Things (IoT) and Wearable Devices: What do the new uses of wireless technologies mean for radio frequency exposure?" GSMA white paper, September 2017

[GSMA2017b] GSMA. “The European Electronic Communications Code Recommendations to the Co-Legislators” GSMA white paper, November 2017 https://www.gsma.com/gsmaeurope/wp-content/uploads/2017/11/GSMA_Recommendations_Code_Nov2017.pdf

[Halilovic2016] E. Halilovic. "EMEA Radio Access Outlook: From LTE to 5G" IDC Technology Assessment - DOC #EMEA40714316, April 2016

[Holma2016] H. Holma, A. Toskala and J. Reunanen. "LTE Small Cell Optimization: 3GPP Evolution to Release 13" Wiley, January 2016

[ICNIRP1998] ICNIRP (1998), “ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)” Health Physics, Vol. 74, No. 4; pp. 494-522. http://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf

[IEC2017] IEC, “Determination of RF Field Strength and SAR in the Vicinity of Radio Communication Base Stations for the Purpose of Evaluating Human Exposure” IEC 62232:2017, August 2017

[IEEE2010] IEEE, “IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Standard C95.3.1-2010” February 2010

[ITU2011] ITU “Telecommunications regulation handbook” Report by World Bank, InfoDev, and ITU, 2011 https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-TRH.1-2011-PDF-E.pdf

[ITU-D2017] ITU “Measuring the Information Society Report” Volume 1 and Volume 2, 2017 https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017.aspx

[ITU-T2014] ITU-T “Electromagnetic field (EMF) considerations in smart sustainable cities” ITU-T Focus Group on Smart Sustainable Cities, October 2014 www.itu.int/en/ITU-T/focusgroups/ssc/Documents/Approved.../TR-EMF.docx

[ITU-T2016] ITU-T “Guidance on complying with limits for human exposure to electromagnetic fields” ITU-T Recommendation K.52, Series K: Protection against Interference, December 2016 https://www.itu.int/rec/T-REC-K.52-201612-I/en

[ITU-T2017] ITU-T “Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields” ITU-T Recommendation K.91, Series K: Protection against Interference, July 2017 https://www.itu.int/rec/T-REC-K.91/en

[ITU-T2017b] ITU-T “Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service” ITU-T Recommendation K.100, Series K: Protection against Interference, July 2017 https://www.itu.int/rec/T-REC-K.100-201707-I/en

[KPMG2016] KPMG “Urban India Real Estate: Promising Opportunities” KPMG report, August 2016 https://assets.kpmg.com/content/dam/kpmg/in/pdf/2016/08/urban_realestate.pdf

[Lewicki2017] F. Lewicki, "Impact of 5G technology on human exposure" ETSI-ITU joint Workshop Towards Setting Environmental Requirements for 5G, ETSI, Sophia Antipolis, France, 23 November 2017

[Li2017] X. Li et al., "Network Slicing for 5G: Challenges and Opportunities," IEEE Internet Computing, vol. 21, no. 5, pp. 20-27, 2017.

[Mao2015] Y. Mao, Y. Luo, J. Zhang and K. B. Letaief, "Energy harvesting small cell networks: feasibility, deployment, and operation," *IEEE Communications Magazine*, vol. 53, no. 6, pp. 94-101, June 2015.

[Masry2016] O. Masry, "Mobile Network Base Station Deployment," Technical paper of the MCF Design and Innovation Programme, 2007 www.tinyurl.com/10wirelesschallenges

[MCF2007] MCF, "10 Key Issues for California Cities & Counties on the Challenges of Small Cells & “Not So Small Cells”," 17 September 2016 http://www.mcf.amta.org.au/files/Plannings.PLDocumentsMCFDesign.and.Innovation.TaskforceMCF.Mobile.Network.Base.Station.Deployment.Technical.Paper.pdf

[Merlini2017] M. Merlini, "Addressing the multi-small cell challenge" JCDecaux presentation at

Small Cell Forum MWC 2017, February 2017 https://www.slideshare.net/SmallCellForum1/addressing-the-multismall-cell-challenge

[mmMagic2015] mmMagic, "Use case characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz," mmMagic deliverable D1.1, November 2015 https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf

[MobileUK2016] Mobile UK, "Code of Best Practice on Mobile Network Development in England" November 2017 http://www.mobileuk.org/cms-assets/documents/259876-147086.code-of-best-practice-2016-edition-pub

[Mozaffari2015] M. Mozaffari, W. Saad, M. Bennis and M. Debbah, "Drone Small Cells in the Clouds: Design, Deployment and Performance Analysis," 2015 IEEE Global Communications Conference (GLOBECOM), San Diego, CA, pp. 1-6, 2015.

[Nagle2009] J. C. Nagle. "Cell Phone Towers as Visual Pollution," Notre Dame Journal of Law, Ethics and Public Policy. Vol. 23, Issue 2, 2009 http://scholarship.law.nd.edu/ndjlepp/vol23/iss2/7

[NARUC2017] NARUC. NARUC Request to expand membership of BDAC, filed in the proceeding captioned: In the Matter of Accelerating Broadband Deployment, GN Docket No. 17-83, 21 August 2017.

[Neumann2017] K.-H. Neumann and T. Plückebaum, "Mobile Network Sharing," 14th ITS Asia-Pacific Conference, Kyoto, Japan, June 24 – 27, 2017.

[NGMN2012] NGMN "Small cell backhaul requirements" NGMN Alliance white paper, June 2012

[Nokia2013] Nokia. "Outdoor 3G/LTE small cells deployment strategy: the race to the pole" Nokia Solutions and Networks Oy, 2013

[Nokia2016] Nokia. "Ultra dense network (UDN) white paper" Nokia Solutions and Networks Oy, June 2016, http://resources.alcatel-luce.com/asset/200295

[Nokia2017] Nokia. "Microwave transport in 4.5, 4.9 and 5G networks" Nokia Oyj, 2017

[Nokia2017b] Nokia. "Ten key rules of 5G deployment: Enabling 1 Tbit/s/km^2 in 2030" Nokia Networks white paper, 2017

[Orange2017] Orange. "A gigabit society deserves a future-proof network access regulation" Part of position papers on Orange views on EECC, October 2017 https://www.orange.com/en/content/download/40219/1266863/version/4/file/EECC_Orange%20position%20_Network.pdf

[Qualcomm2017] Qualcomm and Nokia. "Making 5G a reality: Addressing the strong mobile broadband demand in 2019 & beyond" white paper of Qualcomm Technologies, Inc. and Nokia Oyj, September 2017

[Robson2012] J. Robson. "Small cell deployment strategies and best practice backhaul" Cambridge broadband networks white paper, August 2012

[SCF2012] SCF. "Small Cells: What's the Big Idea?" SCF Report version 030.01.01, February 2012. http://scf.io/en/documents/030_-_Small_cells_big_ideas.php

[SCF2013] SCF. "Release Two – Enterprise" SCF Report version 102.02.01, December 2013.

[SCF2013b] SCF. "Small cell services white paper" SCF Report version 046.07.01, December 2013. http://scf.io/en/documents/046_Small_cell_services.php

[SCF2014] SCF. "Home – Overview" SCF Report version 101.07.03, June 2014. http://scf.io/en/documents/101_Release_One_Home_overview.php

[SCF2014b] SCF. "Deployment issues for urban small cells" SCF Report version 096.07.01, June 2014. http://scf.io/en/documents/096_-_Deployment_issues_for_urban_small_cells.php

[SCF2016] SCF. "Small cell siting: regulatory and deployment considerations", SCF Report version 190.08.02, 5G Americas and Small Cells Forum, December 2016. http://www.5gamericas.org/files/7714/8193/0832/SCF190_Small_cell_siting-final.pdf

[SCF2016b] SCF. "Multi-operator and neutral host small cells Drivers, architectures, planning and regulation", SCF Report version 191.08.02, December 2016. http://scf.io/en/documents/191_-_Multioperator_and_neutral_host_small_cells.php

[SCF2017] SCF. "Simplifying small cell installation: harmonised principles for RF compliance", SCF Report version 182.09.01, February 2017. http://scf.io/en/documents/182_Simplifying_small_cell_installation_Harmonized_principles_for_RF_compliance.php

[SCF2017b] SCF. "Market Status Report" SCF Report version 050.09.01, June 2017.

[SCF2017c] SCF. "Small cells market status report December 2017" SCF Report version 050.10.01, December 2017. http://scf.io/en/documents/050_-_Small_cells_market_status_report_December_2017.php

[SCF2017d] SCF. "Deployment plans and business drivers for a dense HetNet: SCF operator survey" SCF Report version 194.10.01, December 2017. http://scf.io/en/documents/194_Deployment_plans_and_business_drivers_for_a_dense_HetNet_SCF_operator_survey.php

[SCF2017e] SCF. "Densification Summit: Asia Market Requirements" SCF Report version 202.10.01, December 2017. http://scf.io/en/documents/202_-_Densification_Summit_Asia_Market_Requirements.php

[SCF2017f] SCF. "5G era business models and stakeholder engagement" SCF Report version 204.10.01, December 2017. http://scf.io/en/documents/204_-_5G_era_business_models_and_stakeholder_engagement.php

[SCF2017g] SCF. "Vision for Densification into the 5G Era: Release Overview" SCF Report version 110.10.01, December 2017. http://scf.io/en/documents/110_-_Vision_for_Densification_into_the_5G_Era_Release_Overview.php

[SCF2017h] SCF. "Deployment issues for enterprise small cells" SCF Report version 079.10.02, December 2017. http://scf.io/en/documents/079_-_Deployment_issues_for_enterprise_small_cells.php

[SCF2017i] SCF. "Hyperdense HetNets: Definition, drivers and barriers" SCF Report version 180.09.01, February 2017. http://scf.io/en/documents/180_Hyperdense_HetNets_Definition_drivers_and_barriers.php

[Skyworks2017] Skyworks "Top 10 Small Cell Infrastructure Questions" Skyworks Inc white paper, June 2017 http://www.skyworksinc.com/uploads/documents/Top_10_Small_Cell_Infrastructure_Questions.pdf

[Stealth2017] Stealth Concealment Solutions. "Small Cell Solutions" 2017 https://www.stealthconcealment.com/

[TAIPA2017] TAIPA. "Over of the India telecom tower industry" August 2017 http://trai.gov.in/sites/default/files/presentations_&_cv/Day-2_24Aug2017/Session4_Infra%20Sharing/Telecom%20Infrastructure_Umang%20Das_Latest.pdf

[Thielens2017] A. Thielens et al., "Radiofrequency exposure near an attocell as part of an ultra-high density access network" Bioelectromagnetics, Vol. 38, No. 4, pp. 295-306, May 2017

[THORS2017] B. Thors, A. Furuskär, D. Colombi and C. Törnevik, "Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO," IEEE Access, vol. 5, pp. 19711-19719, September 2017 http://ieeexplore.ieee.org/document/8039290/

[TRAI2017] TRAI. "Recommendations on In-Building Access by Telecom Service Providers" January 2017 http://www.trai.gov.in/notifications/press-release/trai-releases-recommendations-building-access-telecom-service-providers

[UN2014] UN. "World Urbanization Prospects" Report of the Population Division of the Department of Economic and Social Affairs of the United Nations, 2014 https://esa.un.org/unpd/wup/

[Yin2009] R. K. Yin. "Case study research: Design and methods" 2nd ed., CA: Sage Publications, Newbury Park, 1994.

[Zarikoff2012] Zarikoff, B., Malone, D., "A Comparison of RF Exposure in Macro- and Femtocells" Health Physics, Vol. 105, No. 1, pp. 39-48, July, 2012.

8 Definition of Terms Used in the Report

Term	Definition
Active sharing	Sharing approach whereby multiple MNOs share some or all active elements of network (e.g. antennas, base station hardware, backhaul interfaces, or even elements of the core network). This includes network-sharing approaches, such as, Multiple operator RAN (MORAN), Multiple operator core network (MOCN) and Gateway core network (GWCN). Active sharing is an enabler for multiple-operator and neutral host small cells. (ITU, Small Cells Forum)
Backhaul	Refers to the network between the base station sites (NodeB, eNodeB, BTS) and the network controller site (RNC, S-GW). (MEF)
Beamforming	Technique used for RF signals to improve quality and performance, by creating multiple signals and finding the best paths, thereby "shaping" the antenna output to provide minimum interference. (Apica)
Carrier	Modulated waveform conveying the physical channels of a radio access link. (3GPP)
Compliance boundary	Surface of arbitrary shape defining a volume outside of which the applicable limit condition is not exceeded. (IEC)
Compliance distance	Distance from the antenna to the compliance boundary for a stated direction and set of transmission conditions. (IEC)
Decisions (EU)	Decisions are EU laws relating to specific cases and directed to individual or several Member States, companies or private individuals. They are binding upon those to whom they are directed. (EU)
Directive (EU)	Directives lay down certain results that must be achieved but each EU Member State is free to decide how to transpose directives into national laws. (EU)
Electromagnetic Field (EMF)	The term 'electromagnetic field' or EMF is used to indicate the presence of electromagnetic radiation. Radio frequency (RF) signals are one type of EMF (and the only EMF considered in this document). The design and deployment of wireless networks must ensure compliance with the required quality of service as well as with the standards and regulations on human exposure to RF EMFs. (ITU)
Equivalent Isotropic Radiated Power (EIRP)	The product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna. (ITU)
Exposure	Exposure occurs wherever a person is subjected to electric, magnetic or electromagnetic fields, or to contact currents other than those originating from physiological processes in the body or other natural phenomena. (ITU)
Exposure level	Exposure level is the value of the quantity used when a person is exposed to electromagnetic fields or contact currents. (ITU)
Exposure ratio (ER)	The assessed exposure parameter at a specified location for each operating frequency of a radio source, expressed as the fraction of the related limit. (ITU)
Femtocell	See Table 1
Fronthaul	Refers to the network between the distributed remote radio heads (RRHs) and a centralised baseband unit (BBU). (Ciena)
General public	All persons not classified as worker (see definition of 'worker' below). (IEC)
GNI per capita	Gross national income divided by mid-year population. GNI per capita in US dollars is converted using the World Bank Atlas method. (UN)
Governance	The way the rules, norms and actions are structured, sustained, regulated and held accountable.
Incident power density (IPD)	IPD is the power per unit area normal to the direction of

	electromagnetic wave propagation, usually expressed in units of Watts per square metre (W/m^2). (ITU)
In-situ RF exposure assessment	Measurement of in-situ RF exposure levels in the vicinity of a radio base station installation after the product has been taken into operation. (IEC)
Isotropic antenna	A hypothetical, lossless antenna having equal radiation intensity in all directions. (ITU)
Main lobe	The radiation lobe containing the direction of maximum radiation. In certain antennas, such as multi-lobed or split-beam antennas, there may be more than one major lobe. (ITU)
Metrocell	See Table 1
Microcell	See Table 1
Multi-operator small cells	Small cells deployed by one MNO and shared by other MNOs (through active sharing). (Small Cells Forum)
Network Function (NF)	Processing functions in a network. (NGMN)
Network Function Virtualization (NFV)	A virtualization technology for implementing processing for network functionality in software running on general-purpose hardware. (NGMN)
Network slicing	Partitioning a single physical network into multiple virtual networks allowing operator to offer optimal support for different types of services and/or different end-users. (NGMN)
Neutral host small cells	Small cells deployed by companies/organisations (typically not MNOs) and shared by multiple MNOs. These neutral hosts (e.g. real estate companies) seek new revenue streams by providing 'small cell infrastructure as service' to MNOs. (ABIResearch, Delta Partners)
Operating band	Frequency range in which a radio access technology operates, that is defined with a specific set of technical requirements. (3GPP)
Output power	Mean power of one carrier of the base station, delivered to a load with resistance equal to the nominal load impedance of the transmitter.
Passive sharing	Sharing approach whereby multiple MNOs share physical space and site infrastructure (masts, utility poles, advertisement panels etc.), but the network elements remain separate. (ITU)
Permits for small cell deployment	Permission to deploy a small cell in a given area. The permit typically obtained through administrative processes generally consider the civil aspects of building permits and the compliance with radiofrequency exposure limits. (GSMA)
Picocell	See Table 1
Power density	See IPD
Product compliance	Determination of compliance boundary information for a radio base station product before it is placed on the market. (IEC)
Product installation compliance	Determination of the total RF exposure levels in accessible areas from a radio base station product and other relevant sources before the product is put into service. (IEC)
Radio Bandwidth	Frequency difference between the upper edge of the highest used carrier and the lower edge of the lowest used carrier. (3GPP)
Rated total output power	The mean power for a base station operating in single carrier, multi-carrier, or carrier aggregation configurations that the manufacturer has declared to be available at the antenna connector during the transmitter ON period. (3GPP)
(EU) Recommendation	A recommendation is not binding. A recommendation allows the institutions to make their views known and to suggest a line of action without imposing any legal obligation on those to whom it is addressed. (EU)
(EU) Regulation	Regulations have binding legal force throughout every EU Member State and enter into force on a set date in all the Member States. (EU)

RF field strength	Electric field strength and/or magnetic field strength from a radiofrequency source. (IEC)
Software-Defined Networking (SDN)	A technology for managing physical and logical resources centrally, enabling high-level automation of entire networks. (NGMN)
Spectrum sharing	The simultaneous usage of a specific radio frequency band in a specific geographical area by a number of independent entities. (Ofcom)
Specific absorption rate (SAR)	SAR is a measure of the rate of RF (radiofrequency) energy absorption by the body from the source being measured. SAR is expressed in units of watts per kilogram (W/kg). (FCC)
Total exposure ratio (TER)	The sum of exposure ratios (ERs) of the equipment under test (base station) and other relevant sources.(ITU)
Virtual network function (VNF)	A virtualized version of a network function (NF). (NGMN)
Visual pollution	Visual pollution is an aesthetic issue and refers to the impacts of pollution that impair one's ability to enjoy a vista or view. Visual pollution disturbs the visual areas of people by creating harmful changes in the natural environment. Base station towers and antennas are among infrastructure that could in some cases be considered to be a of cause visual pollution. (Revolvy, others)
Worker	Adult who is generally exposed to RF fields under known conditions and is trained to be aware of potential risks and to take appropriate precautions. (IEC)

9 Appendix: ICNIRP Limits

In this appendix, a synopsis is provided for the ICNIRP guidelines on basic restrictions and reference levels for limiting RF-EMF exposure for both the general public and workers (occupational).

Table 27 ICNIRP basic restrictions [ITU-T2016]

Type of exposure	Frequency range	Current density for head and trunk (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
Occupational	Up to 1 Hz	40			
	1-4 Hz	40/f			
	4 Hz-1 kHz	10			
	1-100 kHz	f/100			
	100 kHz-10 MHz	f/100	0.4	10	20
	10 MHz-10 GHz		0.4	10	20
General public	Up to 1 Hz	8			
	1-4 Hz	8/f			
	4 Hz-1 kHz	2			
	1-100 kHz	f/500			
	100 kHz-10 MHz	f/500	0.08	2	4
	10 MHz-10 GHz		0.08	2	4

NOTE 1 – f is the frequency in Hertz.

NOTE 2 – Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.

NOTE 3 – All SAR values are to be averaged over any 6-minute period.

NOTE 4 – The localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.

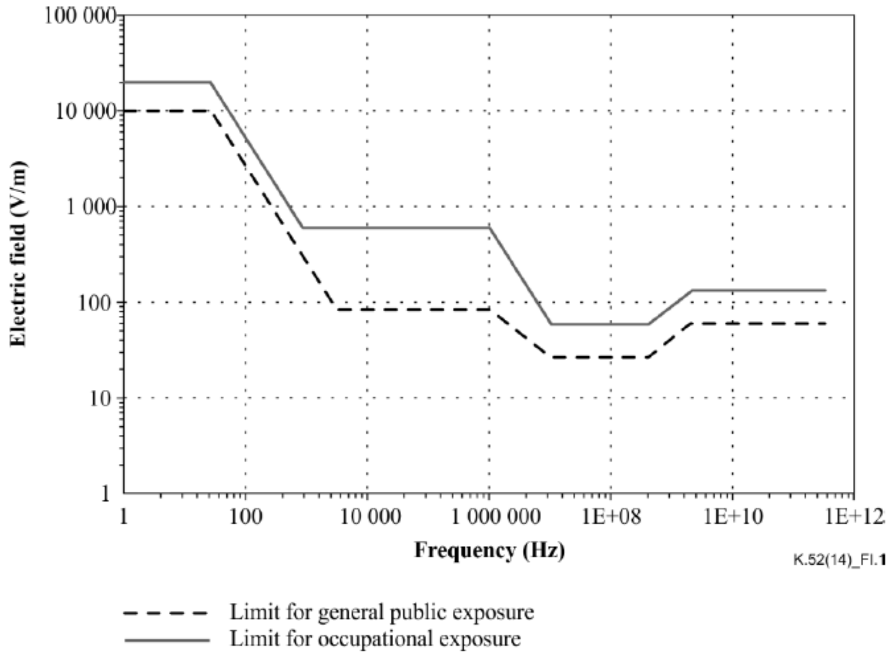


Figure 51 ICNIRP reference levels for electric field strength [ITU-T2016]

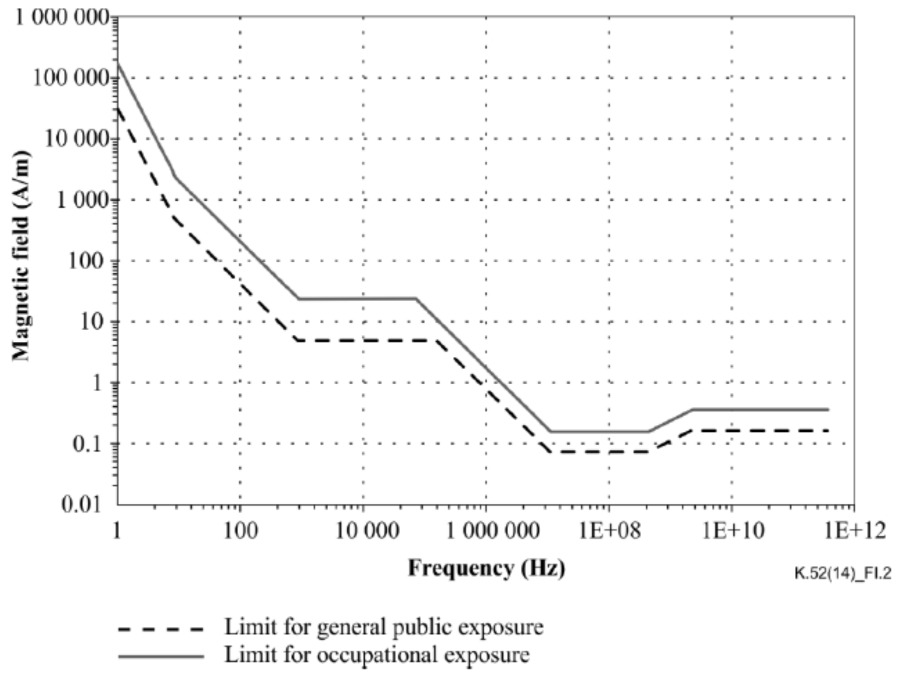


Figure 52 ICNIRP reference levels for magnetic field strength [ITU-T2016]

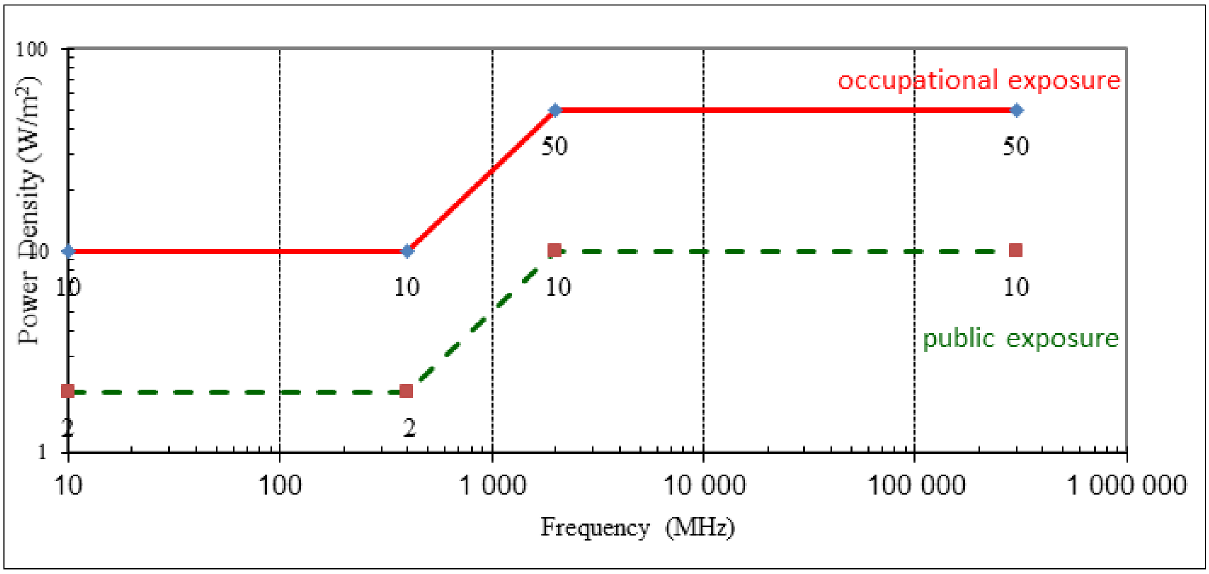


Figure 53 ICNIRP incident power density reference levels above 10 MHz [ITU-T2014]

10 Appendix: Examples of small cells stakeholders

10.1 Supply Category

The example stakeholders of the supply category are listed in Table 28.

Table 28 Example of supply category stakeholders

Supply category stakeholders	**Example stakeholders**
Small cell product manufacturers or vendors	*Airspan*: www.airspan.com Ericsson: www.ericsson.com Huawei: http://www.huawei.com/ Ipaccess: http://www.ipaccess.com/ Nokia: https://networks.nokia.com/ SpiderCloud Wireless: http://www.spidercloud.com/
Site owners, site facility providers, neutral hosts	Wireless Infrastructure Group: http://www.wirelessinfrastructure.co.uk/ Cellnex Telecom: https://www.cellnextelecom.com/en/
Mobile network operators (MNOs)	Example is ETNO members: https://etno.eu/home/about-us/our-members-and-observers
System integrators	Partners of the Nokia Small Cell Site Certification Program: https://networks.nokia.com/solutions/small-cell-site-certification-program Ericsson Small Cells as Service: https://www.ericsson.com/assets/local/news--archive/documents/press-releases/2014/11/small-cell-as-a-service-press-backgrounder.pdf
Application developers	SCF developer community: https://www.smallcellforum.org/press-releases/small-cell-forum-launches-mobile-developer-community/

10.2 Demand category

The example stakeholders of the demand category are listed in Table 29.

Table 29 Example of demand category stakeholders

Demand category stakeholders	Example stakeholders
Individual/private mobile subscribers	n/a
Enterprises	Hilton Hotel London: http://www.smallcellforum.org/site/wp-content/uploads/2016/01/OpenCell_Hilton-Hotel-Bankside.pdf ITRI: http://www.smallcellforum.org/site/wp-content/uploads/2016/06/035_ITRI_20160608_v3.pdf Jakarta airport: http://www.smallcellforum.org/site/wp-content/uploads/2017/07/Ericsson_Jakarta-Airport.pdf

10.3 Governance category

The example stakeholders of the governance category are listed in Table 30.

Table 30 Example of governance category stakeholders

Governance category stakeholders	Example stakeholders
National regulatory authority (NRAs)	List of NRAs for EU MSs: https://ec.europa.eu/digital-single-market/en/national-regulatory-authorities
Local government	Example member list Council of European Municipalities and Regions (CEMR): http://www.ccre.org/

10.4 Advocacy category

The example stakeholders of the advocacy category are listed in Table 31.

Table 31 Example of advocacy category stakeholders

Advocacy category stakeholders	Example stakeholders
Environmental protection entities	European Environment Agency https://www.eea.europa.eu/ List of EMF advocacy groups worldwide: https://www.emf-experts.com/EMF-groups.html
Industry alliances	Small Cells Forum: https://www.smallcellforum.org/ GSMA: https://www.gsma.com/

Advocacy category stakeholders	Example stakeholders
	The European Wireless Infrastructure Association: http://ewia.org/ European Telecommunications Network Operators' Association: https://etno.eu/ Northeast DAS & Small Cell Association (NEDAS): https://www.nedas.com/contact Telecommunications Infrastructure Association (TIA): https://www.tiaonline.org/
Consumer rights bodies	National consumer organisations for different EU MSs[67]
Research community	5G PPP Phase 1 and Phase 2 projects: https://5g-ppp.eu/5g-ppp-phase-1-projects/ https://5g-ppp.eu/5g-ppp-phase-2-projects/
Technology analysts	Rethink Technology Research: http://rethinkresearch.biz/ Wade4wireless: www.wade4wireless.com ThinkSmallCell: https://www.thinksmallcell.com/

67 http://ec.europa.eu/consumers/eu_consumer_policy/consumer_consultative_group/national_consumer_organisations/index_en.htm