Study of the exposure of the general public to radio waves

Simulation of the changes to the exposure of the general public created by mobile telephony in very dense urban areas (Paris XIV)

Intermediate report

August 2020

Executive summary

The deployment of 4G networks and the associated *refarming* , namely the reuse by 4G of the 2G and 3G frequency bands, as well as the perspectives of a commercial 5G deployment in the 3.4-3.8 GHz band, leads to questions on the changes to the exposure of the general public to radio-frequency electromagnetic fields. To study these changes, the National Frequency Agency (ANFR) analysed digital simulations of exposure levels created by mobile telephony in a highly dense urban area, the 14th district (*arrondissement*) of Paris.

The ANFR defined four initial scenarios after discussions with telecommunications equipment manufacturers and mobile phone operators, and after monitoring the 5G pilots completed by the operators.

The first scenario consisted in modelling the current state of the mobile networks in the district composed of a mix of 2G, 3G and 4G technology ("Initial state" scenario).

The second scenario was defined to reflect the final optimisation of 4G ("optimised 4G" scenario): conversion of most 2G and 3G transmitters to 4G technology with accompanying increase in power to increase available speeds. 4G would be deployed on all existing stations and on all current frequency bands except for 900 MHz which would host 2G and 3G.

A third scenario then consisted in modelling the exposure caused by commissioning 5G in the 3.5 GHz band ("5G only" scenario) using beam steering antennas.

A final scenario was created combining the "optimised 4G" and "5G only" scenarios. This theoretical construction will probably never see the light of day because the deployment of 5G will cut short 4G optimisation. Nevertheless, it makes it possible to have an exposure upper bound ("5G upper bound" scenario), because the actual network power in the district should never exceed that level.

The "optimised 4G" scenario reveals that a possible delay to 5G would not result in the stabilisation of the current exposure levels; indeed, it would see a significant increase in exposure in dense areas to allow the 4G network to attempt to cater to part of the expected increase in traffic.

The "5G only" scenario results in a moderate increase in exposure: the average level remains low compared to the exposure limit values of between 36 V/m and 61 V/m. The average level created by 5G in a very dense urban environment in particular is 0.76 V/m inside buildings and behind single glazing. It shows that the 5G beam steering antennas in the 3.4-3.8 GHz band in the long term should not be the main contributors to exposure, including in dense urban areas where these antennas should be widely deployed.

Finally, the "5G upper bound" scenario shows an increase in the average exposure in the order of 30 compared to the "optimised 4G" scenario when the implementation of the new 3.5 GHz band will have simultaneously increased the assigned operator frequencies by 50%. This increase should be put into perspective with the 70% increase found for the "Initial state" and "optimised 4G" scenarios. These levels in particular show the contribution of 5G beam steering antennas in controlling exposure in the new 3.5 GHz frequency band.

This increased exposure will result in an increase in atypical points[1]. In an attempt at sobriety, and in order to keep exposure levels well under the limit values, this increase in the number of atypical points will require increased efforts by operators when designing their networks, efforts that will be controlled by the National Frequency Agency.

This report is an intermediate report. It provides the first order of magnitude for the resulting exposures. The next steps in this work will be to refine the deployment scenarios by varying the technology and powers used in the different frequency bands open to mobile telephony.

[1] Atypical points are defined in particular by an attention value of 6 V/m, which is well below the regulatory limit values.

Exposure will thus be simulated more accurately between the limits formed by the initial state and the 5G upper bounds.

CONTENTS

1. Background

1.1 Mobile networks in the face of increased uses

The volume of data transmitted by mobile networks increases regularly. This phenomenon is the result of our fellows citizens’ need for digital connectivity, the smartphone now seeming to be the digital object best suited to this permanent connectivity. In fact, it is used by the majority (51 %) of users aged 12 and over as illustrated in Figure 1-1, the device the most used to connect to the internet taken from the 2019 digital barometer[2] which also features computers (31 %) and tablets (6 %).

51% (+9 points compared to *2017)*

31% (*- 7* points compared to 2017)

6% (- 1 point compared to 2017)

Source: CREDOC, “Enquêtes sur les conditions de vie et aspirations”.

Figure 1-: device most used to connect to the internet
(Scope: the entire population aged 12 and over in %)

Thus, there were 47.7 million 4G mobile customers at the end of 2018, i.e. 6.1 million more than in 2017. They are at the origin of almost all the 3.6 exabytes of data used in 2018 (+ 66 % in one year) and have thus become big data consumers: 6.6 gigabytes per month on average, or almost 40 % more than in 2017[3].

To meet this demand, mobile operators are offering packs with increasingly large amounts of data. As a result, they must regularly increase their network capacities, and in particular that of the hertzian interface which is used to exchange data between terminals and cell towers using radio frequencies.

To increase hertzian interface capacity, operators have two main possibilities:

- firstly, they can **increase the number of frequency bands used** to interact with terminals. This is the most effective method. Currently, French mobile operators have six main bands that were assigned to them by the State over the years:
    - the 900 MHz and 1800 MHz bands which date from 2G deployment;
    - the 2100 MHz band which came with 3G;

[2] https://www.credoc.fr/publications/barometre-du-numerique-2019
[3] https://www.arcep.fr/cartes-et-donnees/nos-publications-chiffrees/observatoire-des-marches-des-communications-electroniques-en-fiance/marche-des-communications-electroniques-en-fiance-annee-2018-resultats-definitifs.html

- the 700 MHz, 800 MHz and 2600 MHz bands assigned to 4G.

The total frequency assets currently held by the four French operators is thus close to 600 MHz[4]. It will soon increase, in particular when 5G is launched with the bids for the 3.5 GHz band.

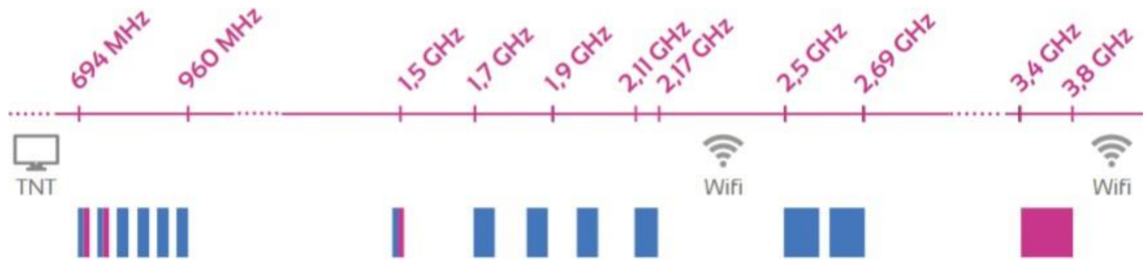

Figure 1-2: distribution of mobile phone frequency bands up to the new 3.4-3.8 GHz 5G band

- The second method consists in **improving transmission efficiency** in each frequency band. There are two ways to do that, neither being exclusive of the other:
  - a first method would be to **increase transmitter power** using the same technology; indeed, signal theory teaches that the improvement of the signal/noise ratio increases data flow: a more powerful transmitter is easier to differentiate from the ambient noise and thereby access higher flows;
  - a second method involves a **change of technology**: 5G is thus more effective for equal spectrum quantities than 4G, which is itself more effective than 3G which had considerably improved the performances of 2G when it was deployed.

Faced with the increased demand for data, the technology change is already under way: the operators have taken advantage of the “technological neutrality” that allows them a free choice of the technology used in the bands they hold, to convert certain bands. Bands specific to 2G have thus become 3G, whereas 3G bands have been transferred to 4G. These changes, known as *refarming*, are not necessarily national: each operator optimises its network according to its own strategy and rhythm as long as they remain within the power limits defined for each cell tower in the authorisation issued by the ANFR.

1.2 5G: new technology and additional frequencies

The imminence of bidding for the 3.5 GHz band has significantly slowed down the work to optimise mobile networks. Indeed, this step will combine the materialisation:

[4] Or on average 200 MHz per operator. But there are differences, the detail is available at https://www.arcep.fr/fileadmin/cru-1589991844/reprise/dossiers/frequences/attributions-frequences- operateurs-mobiles-metropole-sept2019.pdf

- the assignment of an additional 310 MHz to French operators, or an average increase in the order of 50 % of their current hertzian assets in a single frequency band;
- the introduction of more effective technology, 5G, which in the long term can be deployed indiscriminately to all bands authorised for mobile telephony.

In this context, the question of **the changes to the exposure of the general public to electromagnetic fields** is normal. Indeed, if *refarming* has only a marginal effect[5] on the exposure of the general public, the same is not true of the implementation of new frequency bands, nor of the increased power of certain transmitters.

1.3 An iterative approach to control exposure of the general public in dense areas

To study these changes, the National Frequency Agency (ANFR) launched digital simulations of exposure levels in the scenarios representing the evolution envisaged for the networks alongside the Building Scientific and Technical Centre (CSTB). It is important however, to underline the fact that the mobile operators remain fully in control of their network operations: the scenarios considered by each operator to benefit from the different optimisation possibilities remain confidential. **The approach will therefore be iterative**: after a first step which is the publication of this report, other scenarios will be analysed which will show the strategies that will gradually be revealed. In the future, a more precise estimate of the envisaged exposure will therefore become available. This study contributes to analysing changes in exposure and completes the annual measurement analyses conducted by the ANFR[6].

Considering that the stress created by increased use is currently mainly seen in very dense environments, a district in the capital was selected to carry out these simulations: the 14th district of Paris. This area has the advantage of having a relatively high number of cell towers (almost 140 mobile phone cell towers are listed there on the www.cartoradio.fr website) and buildings of varying height. It is also free of coverage issues because the district is already fully covered: different assumptions can therefore be tested without changing the number of antennas.

1.4 The studied scenarios

By convention, the different studied states are referred to as “scenarios”. To define a “point zero” for the change in exposure, the first **“Initial state”** scenario models the current state of the district. As the study was launched in 2018, it corresponds to the mobile phone network situation at the end of 2017 with their 2G, 3G and 4G components. That situation is still very close to the state of the network in 2020.

[5] The effect of the conversion of a 3G band to 4G, or of a 4G band to 5G on exposure is in fact very low in the historic bands that do not use beam steering antennas. On the other hand, converting a 2G band to more advanced technology (3G, 4G or 5G) will reduce exposure for the band in question.[6]

[6] https://www.anfr.fr/controle-des-frequences/exposition-du-public-aux-ondes/la-mesure-de-champ/analyse-des-mesures- realisees/

The ANFR then consulted the telecommunications equipment manufacturers and the mobile phone operators on the products available in the medium and long terms and on the technological deployment strategies that are emerging for the existing sites and frequency bands. An **"Optimised 4G"** scenario was the result: it consists in pushing 4G logic to its conclusion by optimising both transmitter power and the technology used. **It is important to note here that this scenario is currently essentially theoretical**:

- indeed, even though *refarming* (the conversion of existing bands to 4G) has already been partially implemented by several operators, it is likely that the arrival of 5G will quickly put an end to the conversion of bands to 4G. *Refarming* will probably target 5G technology as soon as it becomes available.
- Furthermore, the increase in cell tower power in the 14th district does not seem to have been launched to date.

The "optimised 4G" scenario has another interest: it makes it possible to have an upper bound for the power likely to be implemented in the "historic" bands (from 700 MHz to 2600 MHz) once they are fully optimised - whether for 4G or 5G.

In parallel, a scenario limited to a single frequency band was developed to assess the impact of 5G technology on exposure. This is the **"5G only"** scenario. The logic to this approach consists in creating a robust simulation of the exposure created by beam steering antennas in the 3.5 GHz band. The statistical exposure caused by beam steering antennas is in fact very different from the static exposure created by 2G, 3G or 4G antennas. Once stabilised, this scenario will be combined with various uses of lower frequencies, but can also be transposed to other frequency bands which may, in the future, in turn also benefit from beam steering antennas.

Finally, a first scenario combination is proposed by this intermediate report: it is the combination of the two previously mentioned scenarios ("Optimised 4G" and "5G only") which make up the **"5G upper bound"** scenario. Created by totalling the maximum exposure from the "historic" bands with that of the new 3.5 GHz band, this scenario can indeed be considered *a priori* as an upper bound of the exposure produced if all the optimisation methods were to be activated on all the available bands. **This upper bound may not, however, be reached.** In fact, the conversion of the historic bands to 5G cannot lead to the same increases in power as those considered for 4G, for example.

In the near future, the first real deployment of networks taking into account the assigned licences will make it possible to define scenarios closer to reality and thereby refine the expected changes to exposure.

The first studied scenarios thus provided information on the V/m field level on the ground, on building facades, or in residential locations, taking into account the attenuation due to walls and glazing. These values were also compared to the current level of atypical points (6 V/m) by attempting to assess the number of transmitters that would have to be reconfigured. Indeed, where there are atypical points, the ANFR requires operators to reduce exposure when possible:

the number of transmitters to be modified is therefore an important parameter to size this procedure.

The articulation between the different scenarios is shown in Figure 1-3.

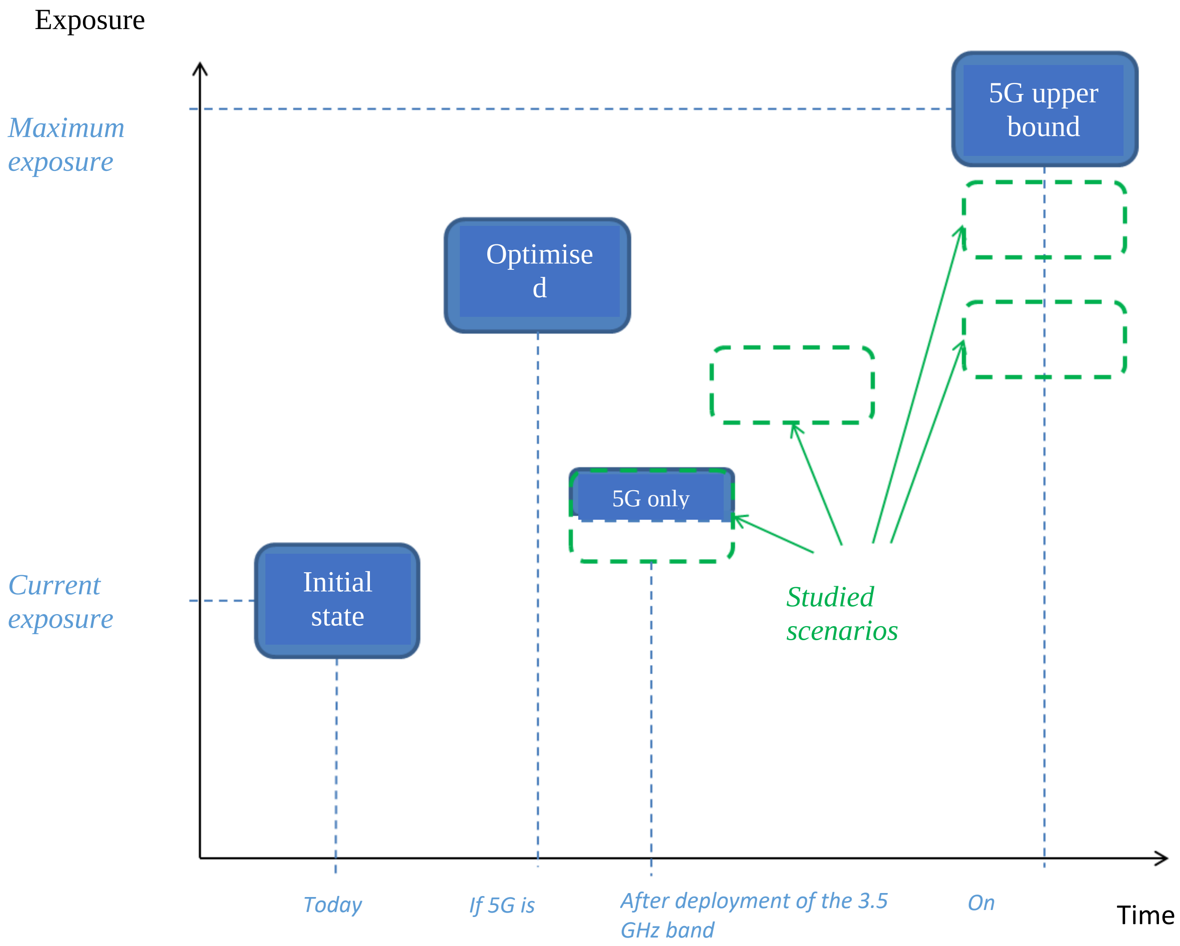

Figure 1-3: presentation of the different scenarios

This report is therefore an intermediate step consisting in laying down some limits in which exposure will be indicated by refining the scenarios at a later date.

The next step will consist in combining the "initial state" and "5G only" scenarios to obtain an estimate of the exposure if 5G deployment is limited to the 3.5 GHz band. Then, using the actual deployment orientations noted in the field, more realistic scenarios involving the conversion of existing bands to 4G or 5G will be developed to assess the resulting exposure, which will in all likelihood be less than that of the "5G upper bound" scenario.

1.5 The simulation method

The electromagnetic field cartography is created using the MithraREM software co-developed by the Building Scientific and Technical Centre (CSTB) and Geomod. MithraREM is software that maps exposure to electromagnetic fields using the calculation of propagation trajectories between radio emitters and the simulation points, taking into account interactions with the environment (reflections, diffraction on buildings and the land). MithraREM uses a "ray tracing" approach combined with geometric optics and the uniform diffraction theory which is well adapted to calculating the exposure around mobile phone antennas.

Warning:

This study is a theoretical analysis using wave exposure simulations. Even if the purpose of the modelling tool used is for informational purposes, its results should be interpreted with caution as they contain significant uncertainties due to the possible sources of error and the limits of the methods used, as was highlighted in particular in the context of the 2011 COMOP/COPIC technical works carried out following the 2009 "Grenelle des Ondes[7]. **Simulations can therefore give information on a trend or on the average change in an area, but can never give a reliable result at a given spot without checking and/or adapting the data**.

The COMIC/COPIC works showed that there were often substantial differences in specific points when comparing the results obtained using MithraREM and the results of measures carried out using the ANFR protocol. In the case of the COMOP, the comparison between measurements and modelling was made at the 128 locations at which detailed measurements were taken in the field. The result was *"satisfactory coherency between measurements and simulation on 40 % of cases"* (report, p. 55), but for the remaining 60 %, the measured levels showed differences from +/-100 % to +/-300 % compared to the modelled levels in approximately 40 % of cases, and were 3 times less than the modelled levels in approximately 20 % of cases.

Later work was able to benefit from this experience and this study, which is based on scenario comparisons, should be all the more robust. However, the purpose of this study is not to precisely identify atypical points in a simulation zone.

2. Regulations covering the exposure of the general public to electromagnetic waves

In France, decree n° 2002-775[8] of 3 May 2002 defines the limit values for the exposure of the general public to electromagnetic waves emitted by equipment used in telecommunications networks or by radio installations. At the international level, these limits were proposed by the international commission on non-ionising radiation protection (ICNIRP), a non-profit officially recognised by the World Health organisation (WHO), in its guide for the definition of limits to the exposure to electric, magnetic and electromagnetic fields in 1998.

[7] http://www.radiofrequences.gouv.fr/IMG/pdf/rapport-copic-31-juillet_2013-1.pdf
[8] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000226401

The European Union adopted those limits in its 1999/519/EC recommendation.

The limit values depending on the frequencies are shown below (see Figure 2-1)

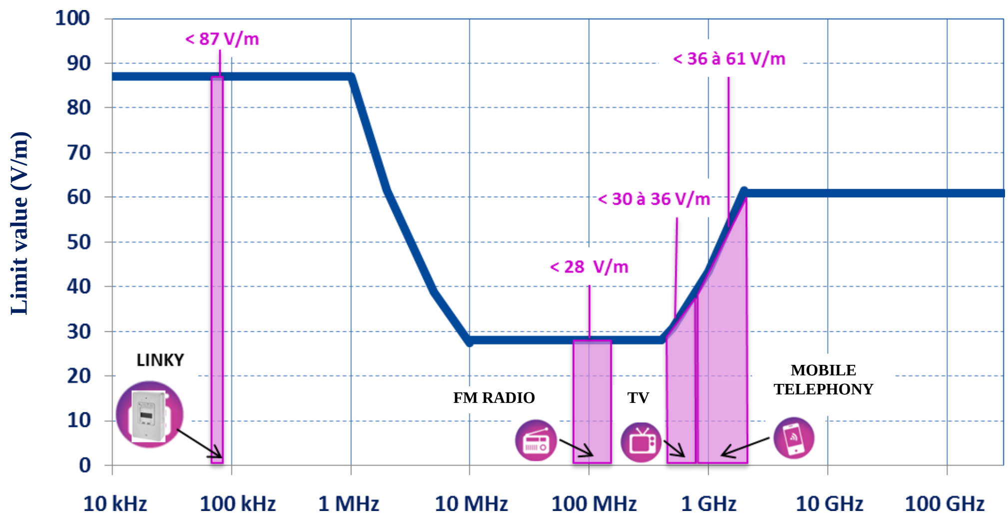

Figure 2-1: regulatory limit values defined in France by decree n° 2002-775 of 3 May 2002

For the remainder of the study, the values will be analysed compared to the 6 V/m attention value selected for atypical points. It can be noted that this value is well below the regulatory thresholds of between 36 and 61 V/m for mobile telephony.

3. Study description

The study is based on simulations carried out by the CSTB based on information provided by the ANFR and regular exchanges between the two organisations.

The study zone, the 14th district of Paris, is representative of a very dense urban zone. A digital model was built using input data (land, buildings and radio transmitters) to which the propagation calculations were applied to estimate the levels of exposure to the electromagnetic fields created by the mobile phone antennas for a set of simulation points. It does not take into account the other sources contributing to the exposure of the general public (FM, TV, wifi transmitters, etc.).

This study essentially compares deployment scenarios. The calculation model (land and buildings) and the calculation method linked to the MithraREM software are identical for each scenario. This relative approach between different states makes it possible to locally do away with the need for a detailed analysis of absolute uncertainties on the results of digital modelling.

4.1 Land and building data

The ANFR provided the CSTB the 2009 IGN 3D built-up area model for the 14th district built from an aerial view. This built-up area model makes it possible to have a precise level of detail (LOD2). The external structure of each building is modelled in 3D, including roof pitches. In the model, the roof and facade data is separated (see Figure 3-1).

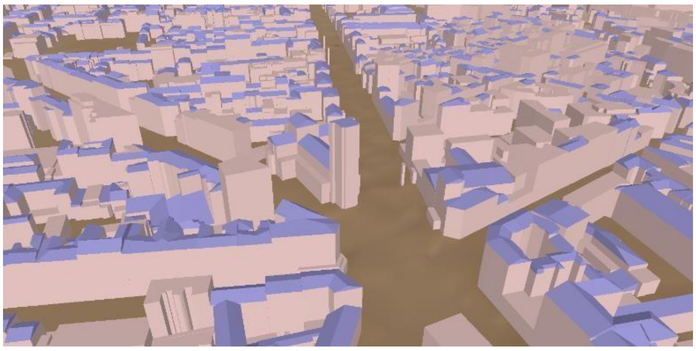

Figure 3-1: example of a 3D view of the IGN model of Paris14 in MithraREM

The land and building model was then compared to a more recent model of the city of Paris[9] dating from July 2017 in order to have the most up-to-date model possible. The data model has little changed since 2009 and the IGN 3D data remains reliable and accurate, bar a few adjustments indicated in Table 3-1.

IGN 3D data	25741 buildings
"City of Paris" data added	149 buildings
Model errors and eliminations	103 buildings
Added buildings	5 buildings

Table 3-1: summary of building data

4.2 Radio transmitter data

The transmitter specifications were provided by the four mobile phone operators. They cover: the precise location of the base stations (address, type of building, land registry map), the orientation (azimuth), the antenna mid-point height, the antenna gain, the mechanical *tilt*, the antenna model, the directivity diagrams, the list of transmitters for each antenna, the emission frequency bands, the electric *tilts* and the maximum emitted power (EIRP).

[9] https://opendata.paris.fr/explore/?sort=modified

To include the transmitters, a manual positioning of the transmitters, a long and painstaking operation essential to avoiding exposure errors, was carried out using the land registry map, resulting *in fine* in a model as close as possible to reality.

In this document, a transmitter is characterised by a frequency band combined with a technology and a sector for a given mobile phone operator.

4.3 MithraREM software parameters

The MithraREM version 1.7 software was used to simulate the different scenarios.

Types of materials must be assigned to each building in the model. This corresponds to the physical properties that lead to the behaviour relative to electromagnetic waves: dielectric permittivity and electric conductivity which result in reflection, diffraction and transmission ratios depending on the frequency, the polarisation and the angle of attack of the wave.

A single material was selected for all the buildings in the studied zone to take into account reflection and diffraction. The building material has the characteristics of a light concrete[10].

For transmission through facades and roofs, the coefficient for single glazing is used, defined in the ANFR guidelines[11] (fixed 20 % attenuation of normal incidence on the electric field level).

Simulation points were taken into account every two metres on building facades and on the ground. The height of the simulation points above the ground in outdoor spaces (streets, public spaces) is 1.5 m.

Roofs were taken into account, exposure levels on flat or slightly pitched roofs[12] were not calculated, in particular those on which cell towers are located which are usually not accessible to the public.

The total number of simulation points for the entire calculation zone is about 3,200,000 (of which 2,100,00 on facades and 1,100,000 above ground level).

For simulation points on facades, two calculations were carried out:

- One outside the facade to take into account the possible existence of balconies: the calculated electric field level is obtained from the incident levels (from each transmitter and the multiple reflections and diffractions[13] in the environment) including those from the reflection on the facade itself (light concrete equivalent);
- the other behind the facade, inside the building ("after the first wall"): the electric field level calculation behind building facades uses the incident levels outside the facade and a statistical model of wave transmission through the facades.

[10] The relative dielectric permittivity value is: $\varepsilon = 6$
The electric conductivity value is: σ 0.003 S/m
[11] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/20191001-Lignes-directrices-nationales.pdf
[12] A difference between altitude $Z_{\text{minimum roof}}$ and altitude $Z_{\text{maximum roof}}$ of less than 0.75 metres
[13] Reflection and diffraction by horizontal edges taken into account

This model takes into account the angle of attack of each propagation trajectory and of the fixed attenuation factor for the facade equivalent to single glazing.

The attenuation hypotheses for the different crossed surfaces are thus an upper bound, because the attenuation by single glazing is less than for light concrete and also less than for double glazing.

4.4 Simulation scenario descriptions

3.4.1 "Initial state" scenario

The "initial state" scenario is based on a reference state composed of data provided by the operators in December 2017.

For this scenario, the different frequency bands and technology available are given in Table 3-2. On a given site, the frequency bands are not always installed.

Frequencies	Initial state
700 MHz	4G
800 MHz	4G
900 MHz	2G and 3G
1800 MHz	2G and 4G
2100 MHz	3G
2600 MHz	4G

2G = GSM   3G = UMTS   4G = LTE

Table 3-2: technology/frequency pairs - "Initial state" scenario

3.4.2 "Optimised 4G " scenario

The ANFR defined this scenario for future deployment after consulting the telecommunications equipment manufacturers and the mobile phone operators on the products available in the medium and long terms on the market, and on the technological deployment strategies that are emerging for the existing sites and frequency bands. This scenario is built on the assumption of evolutions in the deployment of 2G, 3G and 4G transmitters, and corresponds to the deployment of 4G on all existing stations and all current frequency bands, except for the 900 band which would continue to house 2G and 3G (see Table 3-3). This scenario is named "optimised 4G". It does not cover 5G which is the subject of a separate analysis.

The result is that for each azimuth for each base station at the initial state:

- all the operator frequency bands are used: 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz, contrary to the initial scenario in which not all stations used all frequencies;
- 4G technology is present in the 700 MHz, 800 MHz, 1800 MHz, 2100 MHz and 2600 MHz bands;
- 2G and 3G technology is only present in the 900 MHz band;
- for the 700 MHz, 800 MHz and 900 MHz bands, the input powers are similar to those used in the initial state; where data is missing, the antenna powers in the adjacent bands are used;
- for the 1800 MHz, 2100 MHz and 2600 MHz bands, the input powers are increased to 4x40W, or equal to the input power for the initial state when it is already greater than 4x40W; this increase in power makes it possible to improve the signal/noise ratio and therefore increase the working flow of the existing 4G antennas;
- The antenna type (model, diagram) and characteristics (mechanical, electric *tilt* , etc.) of the missing antennas use the characteristics of the antennas in the adjacent bands.

Frequencies	“Initial state”	“Optimised 4G”	
700 MHz	4G	4G	
800 MHz	4G	4G	$P = P_{\text{initial state}}$
900 MHz	2G and 3G	2G and 3G	
1800 MHz	2G and 4G	4G	
2100 MHz	3G	4G	P = 4 x 40 W
2600 MHz	4G	4G	

2G = GSM 3G = UMTS 4G = LTE

Table 3-3: technology/frequency pairs - “Initial state“ scenario and “optimised 4G “ scenario comparison

The maximum transmitter power was reduced by a reduction factor (1.6x1.6) which corresponds to the factor of 1.6 applied at the electric field level and defined in the ANFR guidelines[14], in order to model the exposure measured in the field using a wide band probe.

3.4.3 “5G only“ scenario

Only 5G is considered in a single band (3.5 GHz band), without taking into account the other mobile telephony contributors. This scenario is named “5G only”.

For 5G, deployment is systematically in the 3.5 GHz band on all existing sites:

- the locations, layouts and azimuth of the 5G transmitters are identical to those of the 4G antennas;

[14] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/20191001-Lignes-directrices-nationales.pdf

- 80 MHz per operator are assigned to the 3.5 GHz band;
- the injected power was selected based on the observations made during the pilots (200 W for 100 MHz of band) which gives 160 W (or 52.04 dBm) for a bandwidth of 80 MHz;
- the mechanical *tilt* is nil;
- a generic envelope diagram is used for all the 5G antennas: it uses the technical specifications for the *Massive MIMO* system presented in appendix H of document IEC TR 62669 (horizontal opening at -3 dB of 120°, vertical opening at -3 dB of 40°, 20 dB attenuation beyond that; electric *tilt* of -3° included).

As the input powers and radiation diagrams are identical, the EIRP (Equivalent Isotropically Radiated Power) for 5G antennas is identical for each operator:

$$EIRP = P_{input} + Gain = 52.04\ dBm + 24.3\ dBi = 76.34\ dBm$$

The "5G only" scenario is simulated using a reduction factor of 14.75 dB on the radiated power to take into account the temporal duplexing (1.25 dB) and the beam sweep averaged over 6 minutes (13.5 dB) in compliance with ANFR guidelines[15].

3.4.4 "5G upper bound" scenario

The contributions of the "optimised 4G" scenario (scenario optimised without 5G) and the "5G only" scenario are combined to create the future "5G upper bound" scenario.

A priori 5G and 4G technology generate similar exposure for a given frequency band for static beam antennas. Now, it seems that classic static beam antennas must mainly be used in the bands previously used by 4G. As a result, even if 5G can in principle create an exposure *a priori* slightly lesser for a given use, this scenario is a plausible upper bound for the case of migration from 4G to 5G.

The final result makes it possible to illustrate the strategic trend according to which the mobile operators want to avoid deploying new sites and the deployment of new frequency bands.

A summary of the "5G upper bound" scenario is shown below in Table 3-4.

[15] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/20191001-Lignes-directrices-nationales.pdf

Frequencies	“Initial state” scenario	“Optimised 4G” scenario	“5G upper bound” scenario	Input power for the future scenarios
700 MHz	4G	4G	4G	$P = P_{initial\ state}$
800 MHz	4G	4G	4G	$P = P_{initial\ state}$
900 MHz	2G and 3G	2G and 3G	2G and 3G	$P = P_{initial\ state}$
1800 MHz	2G and 4G	4G	4G	P = 4 × 40 W
2100 MHz	3G	4G	4G	P = 4× 40 W
2600 MHz	4G	4G	4G	P = 4 × 40 W
3600 MHz			Antenna	P = 160 W

Table 3- 4: Summary of the “5G upper bound” scenario

4. Simulation results

The results are given for the different scenarios. A study in the changes to exposure between the different scenarios is then given.

4.1 “Initial state“ scenario

The average and median electric field levels calculated on all the simulation points in the 14th district of Paris area are given in Table 4-1. The highest electric field levels are shown by the maximum calculated value for 99 % of the simulation points.

	Median level	Average level	1 % of the calculated points are greater than
Calculations above ground level	0.6 V/m	0.8 V/m	2.9 V/m
Calculations in front of facades (outdoors)	0.8 V/m	1.1 V/m	5.2 V/m
Calculations behind facades (indoors)	0.4 V/m	0.6 V/m	3.1 V/m

Table 4-1: summary of “initial state“ scenario calculation results

These results can be compared with the results of measurements of exposure of the general public to electromagnetic waves made in 2017 as part of the national monitoring system[16] where the median level had been raised to 0.4 V/m in urban environments where most measurements are taken indoors which, even if the results are not directly comparable, makes it possible to have a good level of confidence on the quality of the simulations carried out in the "initial state" scenario.

The distribution of exposure levels is shown in Figure 4-1.

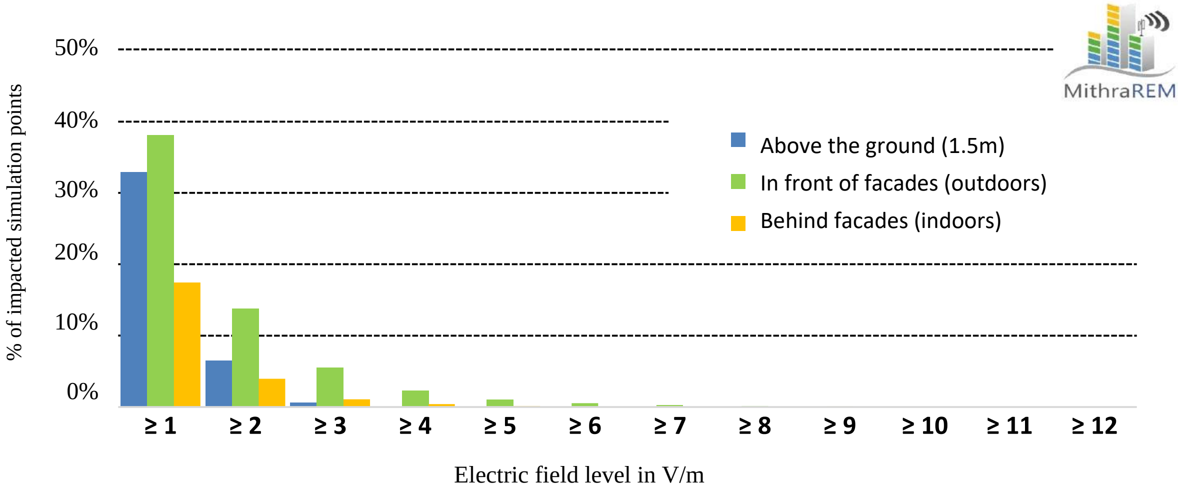

Figure 4- 1: Total exposure distribution - "Initial state" scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	32.9%	6.5%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	38.1%	13.8%	5.5%	2.3%	1.1%	0.6%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%
	17.4%	4.0%	1.1%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The electric field level is the result of contributions from several transmitters. In front of facades, outdoors, they are statistically slightly higher than the exposure levels on the ground. This result is coherent with building density, transmitter density and with the network architecture with transmitters placed at high points: roofs, tops of facades. The simulated exposure levels on the ground can nevertheless be a good indicator of the exposure at a district level as shown by the COMOP results[17].

Exposure behind facades, indoors, is highly reduced compared to outdoor exposure. This is due to the 20 % attenuation factor through the facade, to which is added the angle of attack of propagation trajectories on the facade, with a high reduction in the electric field penetration with very small angles. In reality, the attenuation could be higher, for example, in the presence of double glazing.

[16] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/20180919-Analyse-mesures-2017.pdf
[17] http://www.radiofrequences.gouv.fr/IMG/pdf/rapport-copic-31-juillet_2013-1.pdf

The simulation points for buildings in excess of 6 V/m represent 0.69 % of the outdoor points and 0.1 % of the points inside buildings.

The contribution of transmitters to exposure levels is shown in Figure 4-2. Please remember, a transmitter is characterised by a frequency band combined with a technology and a sector for a given mobile phone operator. Thus, the field per transmitter level is not the overall exposure level.

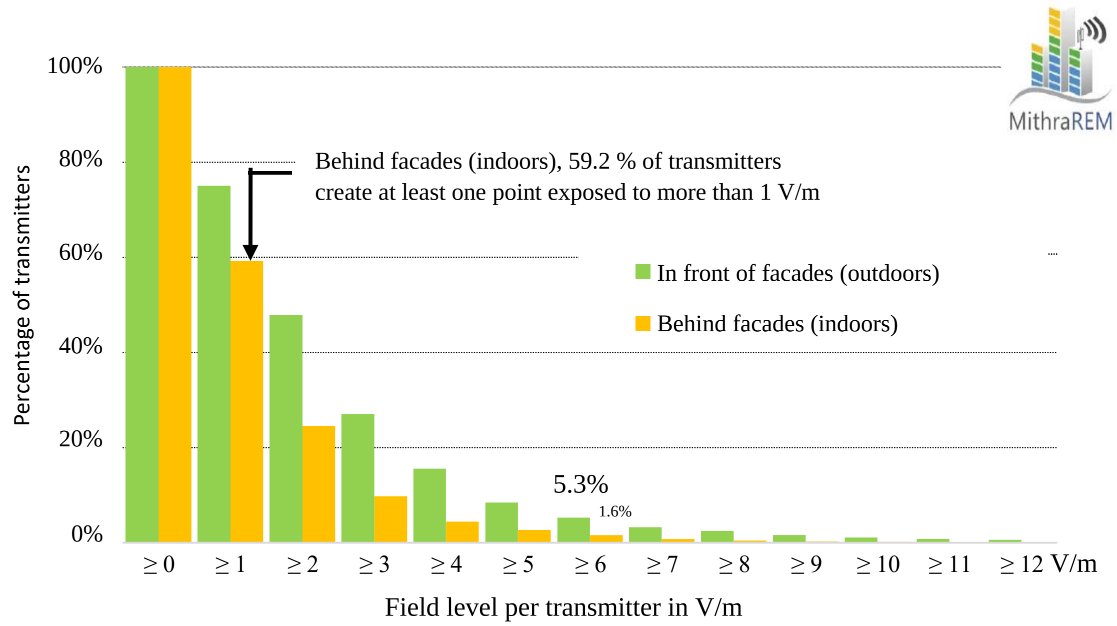

Figure 4- 2: Total contributor transmitter distribution - Initial state" scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	75%	47.8%	27.1%	15.6%	8.4%	5.3%	3.2%	2.5%	1.6%	1.1%	0.8%	0.6%
	59.2%	24.6%	9.8%	4.4%	2.7%	1.6%	0.8%	0.5%	0.3%	0.2%	0.2%	0.2%

In the "Initial state" scenario, over 59% of the installed transmitters generate at least one point greater than or equal to 1 V/m inside the buildings. 75 % of the installed transmitters generate at least one point greater than or equal to 1 V/m outside the buildings. Over 5 % of the installed transmitters generate at least one simulation point greater than or equal to 6 V/m outside the buildings. Finally, less than 2 % of the installed transmitters generate at least one simulation point greater than 6 V/m inside the buildings.

Figure 4-3 shows an example of the calculated electric field levels behind facades, inside buildings.

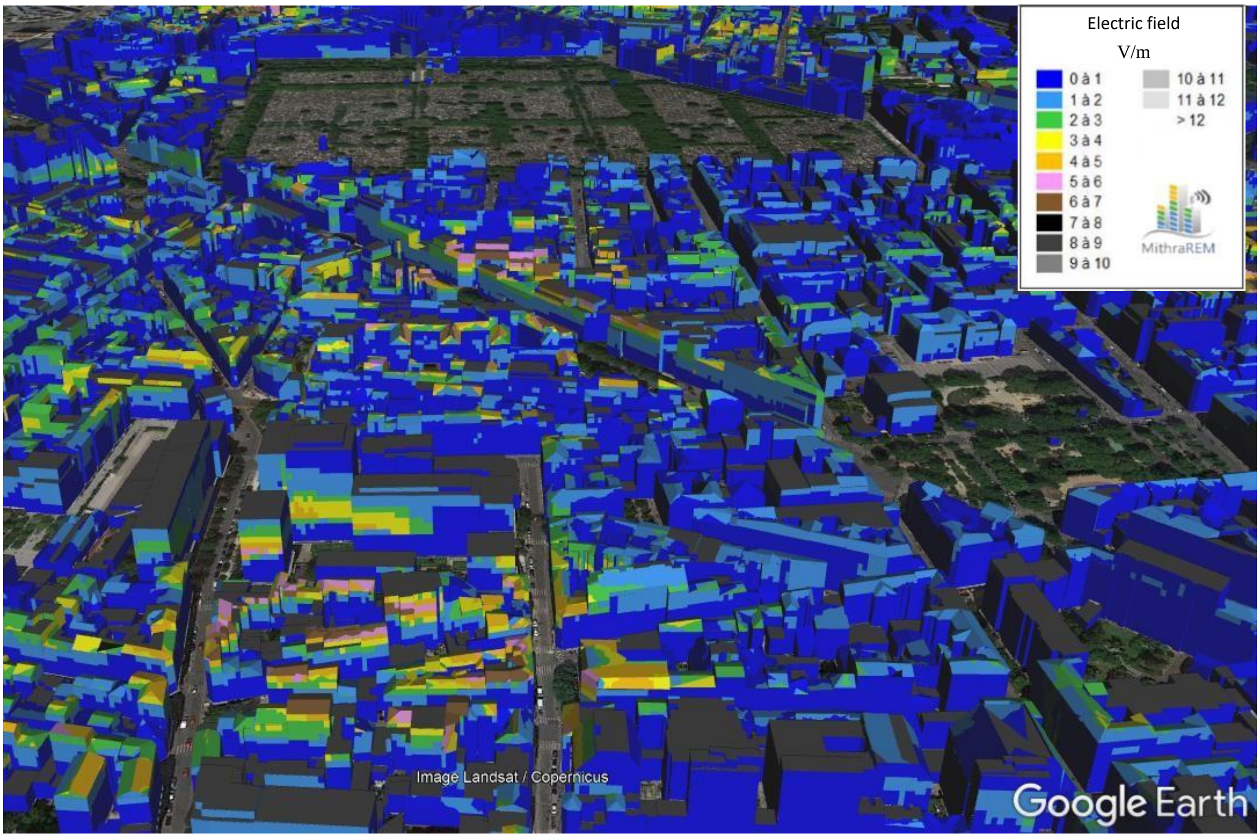

Figure 4-3: example of calculated electric field levels behind building facades indoors - "Initial state" scenario (Google Earth view)

4.2 "Optimised 4G " scenario

Using the assumptions of the "Optimised 4G " scenario, the average and median electric field levels calculated on all the simulation points in the 14th district of Paris zone are given in Table 4-2 : the highest electric field levels are shown by the maximum calculated value for 99 % of the simulation points..

	Median level	Average level	1 % of the calculated points are greater than
Calculations above ground level	1.0 V/m	1.3 V/m	4.8 V/m
Calculations in front of facades (outdoors)	1.3 V/m	1.8 V/m	8.6 V/m
Calculations behind facades (indoors)	0.6 V/m	1 V/m	5.2 V/m

Table 4-2: summary of the "optimised 4G" scenario calculation results

Compared to the simulated "Initial state" scenario (which corresponds to the state of the networks in 2017), there is an increase, in particular at the median level which passes from 0.4 V/m to 0.6 V/m indoors.

In the 2019 measurements[18] the median level rose to 0.45 V/m in urban environments where the median level in urban environments was 0.4 V/m in our measurements taken in 2017. **The increase seen on the simulations is therefore not yet visible in the measurements: *a priori* this means that this deployment assumption was not yet a fact in 2019.**

The distribution of exposure levels is shown in Figure 4-4.

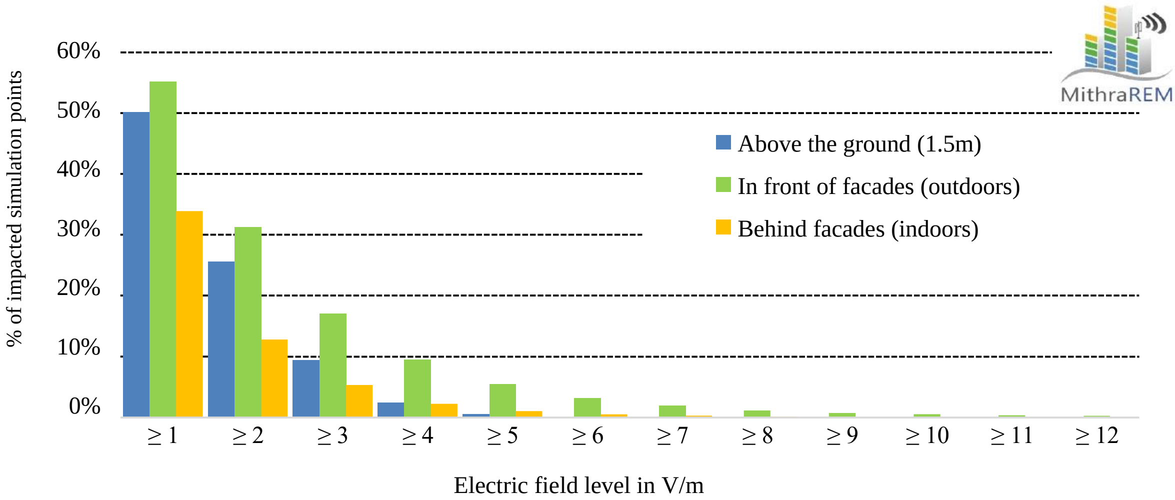

Figure 4- 4: Total exposure distribution - "Optimised 4G " scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	50.1%	25.6%	9.4%	2.4%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	55.2%	31.2%	17.0%	9.4%	5.5%	3.2%	1.9%	1.2%	0.7%	0.5%	0.3%	0.2%
	33.9%	12.8%	5.3%	2.3%	1.1%	0.5%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%

The contribution of transmitters to exposure levels is shown in Figure 4-2. Please remember, a transmitter is characterised by a frequency band combined with a technology and a sector for a given mobile phone operator.

[18] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/20200408-ANFR-analyse-mesures-2019.pdf

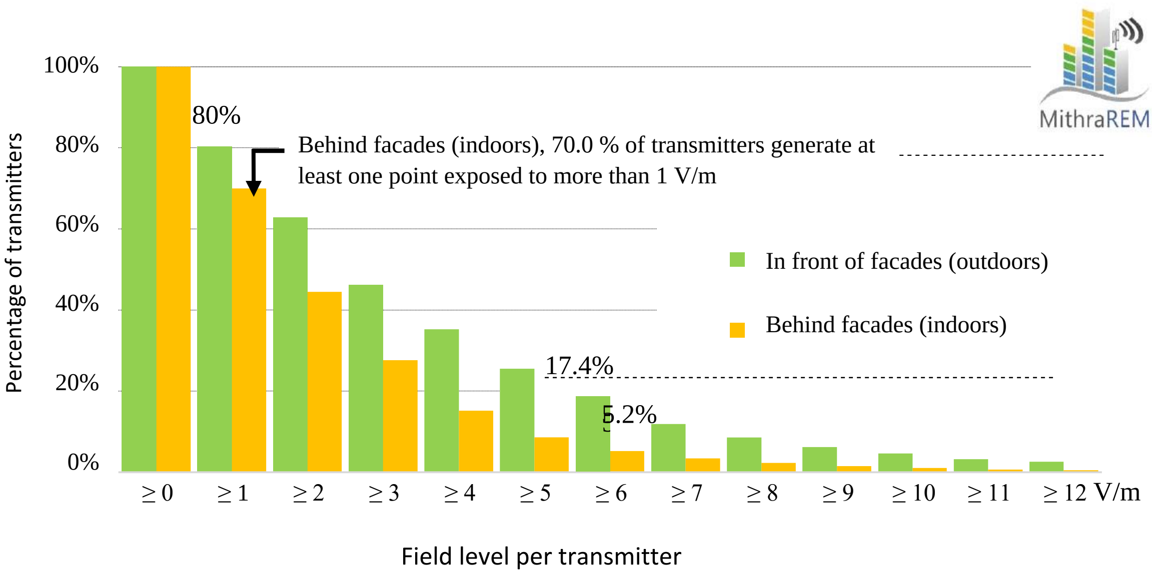

Figure 4- 5: Total contributor transmitter distribution - "optimised 4G " scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	80.3%	62.8%	46.2%	35.2%	25.5%	17.4%	11.9%	8.6%	6.2%	4.7%	3.3%	2.6%
	70.0%	44.5%	27.6%	15.1%	8.6%	5.2%	3.4%	2.3%	1.5%	1.0%	0.7%	0.5%

The contribution of this scenario, in particular in the light of the controversy surrounding the deployment of 5G, is to show that a hypothetical freeze of technological change would not stabilise the exposure of the general public at the current levels: **in order to meet the increased demand for mobile data, the 4G optimisation logic would lead to increased exposure in dense areas.**

4.3 "5G only " scenario

In the "5G only " scenario, only 5G is simulated in a single band without the other technology. The results are analysed in this report, even if the main study objective is the analysis of overall exposure levels created by mobile telephony.

Table 4-3 below shows a summary of the results.

	Average level	Percentage of points above 6 V/m
Calculations in front of façade (outdoors)	1.36 V/m	1.1 %
Calculations behind facades (indoors)	0.76 V/m	0.2 %

Table 4- 3: Summary of the results for the "5G only " scenario

Figure 4-6 below shows the exposure level distribution

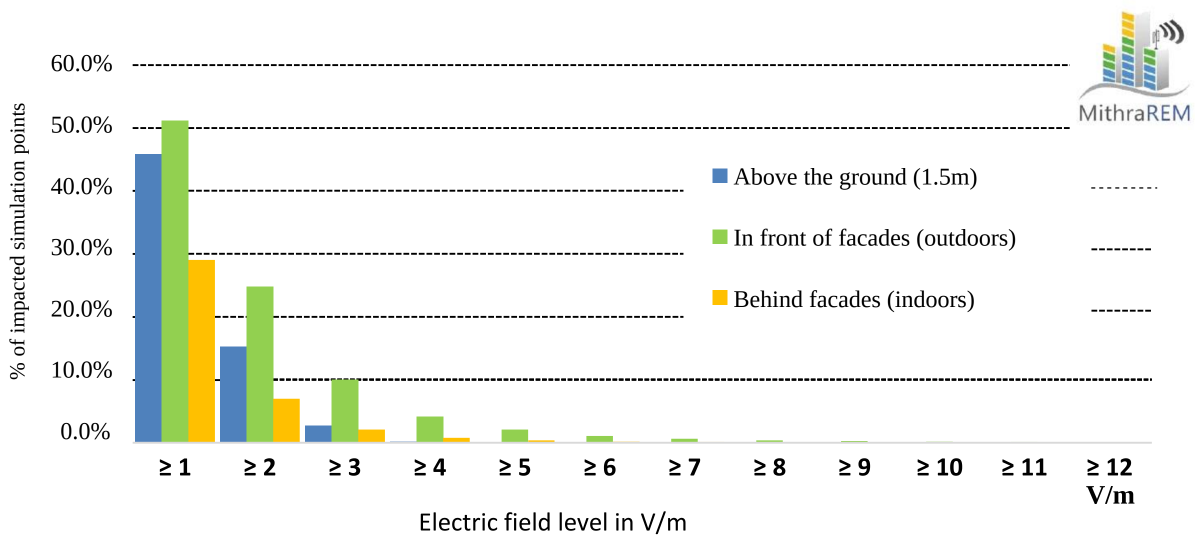

Figure 4- 6: Exposure level distribution for "5G only"

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	45.9%	15.3%	2.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	51.2%	24.8%	10.1%	4.1%	2.1%	1.1%	0.6%	0.4%	0.3%	0.2%	0.1%	0.1%
	29.0%	7.0%	2.1%	0.8%	0.4%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%

Outdoors, in front of the facades, the percentage of points above 6 V/m is 1.1 %, it is higher than the percentage for the initial state (0.6 %) but much lower than the percentage for the "optimised 4G " scenario (3.2 %). Similarly, the average exposure for outdoor facades is 1.36 V/m higher than the one for the initial state (1.1 V/m) and lower than the one for the "optimised 4G " scenario (1.8 V/m).

The 5G beam steering antennas in the 3.4-3.8 GHz band compared to the classic static beam antennas in the selected hypotheses should therefore not be the main contributors to exposure, including in dense urban areas where these antennas should be widely deployed.

4.4 "5G upper bound" scenario

The average and median electric field levels calculated on all the simulation points in the 14th district of Paris zone are given in Table 4-4. The highest electric field levels are shown by the maximum calculated value for 99 % of the simulation points.

	Median level	Average level	1 % of the calculated points are greater than
Calculations above ground level	1.5 V/m	1.7 V/m	5.6 V/m
Calculations in front of facades (outdoors)	1.8 V/m	2.3 V/m	10.4 V/m
Calculations behind of facades (indoors)	0.9 V/m	1.3 V/m	6.3 V/m

Table 4-4: summary of "5G upper bound" scenario calculation results

The distribution of exposure levels is shown in Table 4-7.

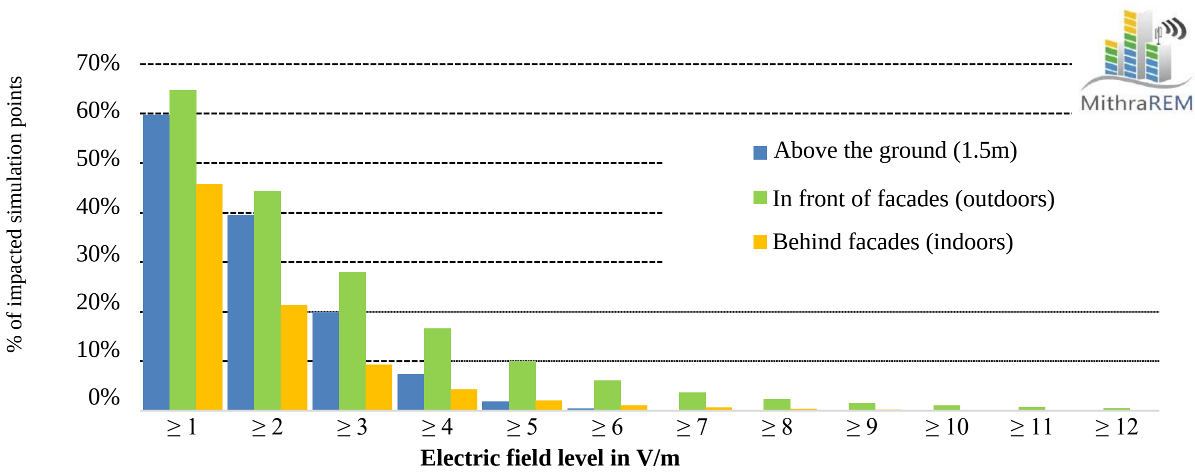

Figure 4-7: total exposure distribution - "5G upper bound" scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	59.8%	39.5%	19.9%	7.4%	1.9%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	64.7%	44.4%	28.1%	16.6%	9.9%	6.1%	3.7%	2.4%	1.6%	1.1%	0.8%	0.5%
	45.8%	21.3%	9.3%	4.3%	2.1%	1.1%	0.7%	0.4%	0.2%	0.1%	0.1%	0.1%

The contribution of transmitters to exposure levels is shown in Table 4-8. Please remember, a transmitter is characterised by a frequency band combined with a technology and a sector for a given mobile phone operator.

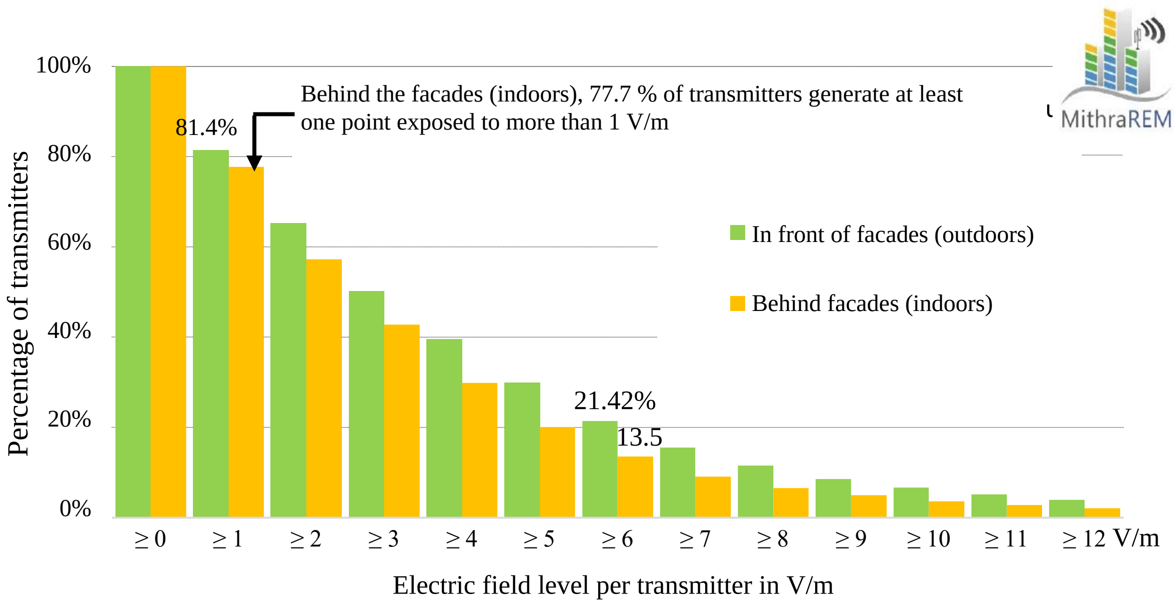

Figure 4-8: Total contributor transmitter distribution - "5G upper bound" scenario

	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6	≥ 7	≥ 8	≥ 9	≥ 10	≥ 11	≥ 12
	81.4%	65.3%	50.2%	39.6%	29.9%	21.4%	15.5%	11.5%	8.6%	6.6%	5.2%	3.9%
	77.7%	57.2%	42.7%	29.9%	20.1%	13.5%	9.1%	6.5%	4.9%	3.6%	2.7%	2.0%

4.5 Exposure evolution

The evolution of exposure is studied separating exposure in front of facades (outdoors) and behind facades (indoors) and on the ground.

4.5.1 Evolution of exposure behind facades (indoors)

To study the evolution behind facades (indoors) according to the different scenarios, below the distribution of exposure is shown with the average and the number of points that generate an exposure value greater than or equal to 6 V/m, as well as the distribution of transmitters contributing to the exposure with the percentage of transmitters generating a point for which the exposure is greater than or equal to 6 V/m.

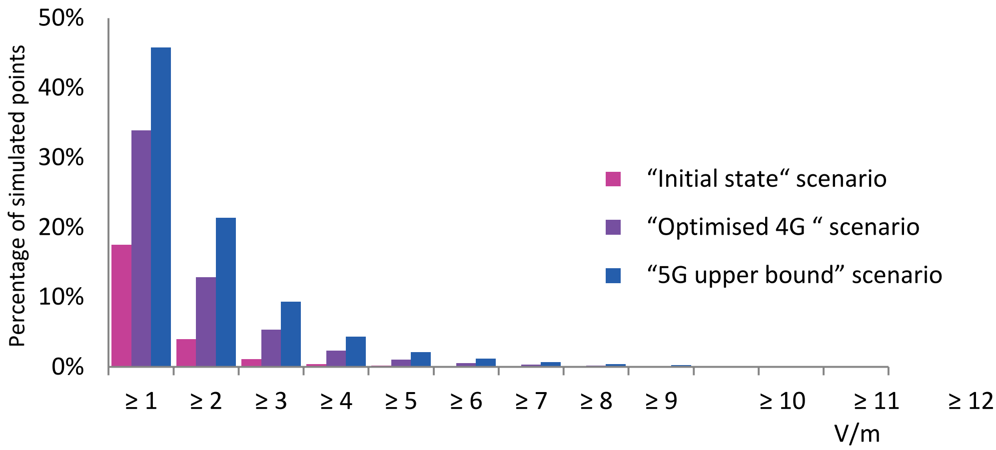

Figure 4- 9: total exposure distribution behind facades (indoors)

	"Initial state" scenario	"Optimised 4G" scenario	"5G upper bounds" scenario
Average	0.6 V/m	1 V/m	1.3 V/m
Percentage of points ≥ 6 V/m	0.07 %	0.5 %	1.1 %

Table 4- 5: evolution of exposure behind facades (indoors)

Exposure increases behind facades (indoors) depending on the scenario, the number of points greater than or equal to 6 V/m is multiplied by 15 indoors, even if the percentage is low for the last scenario (1.1 %) (see Table 4-5).

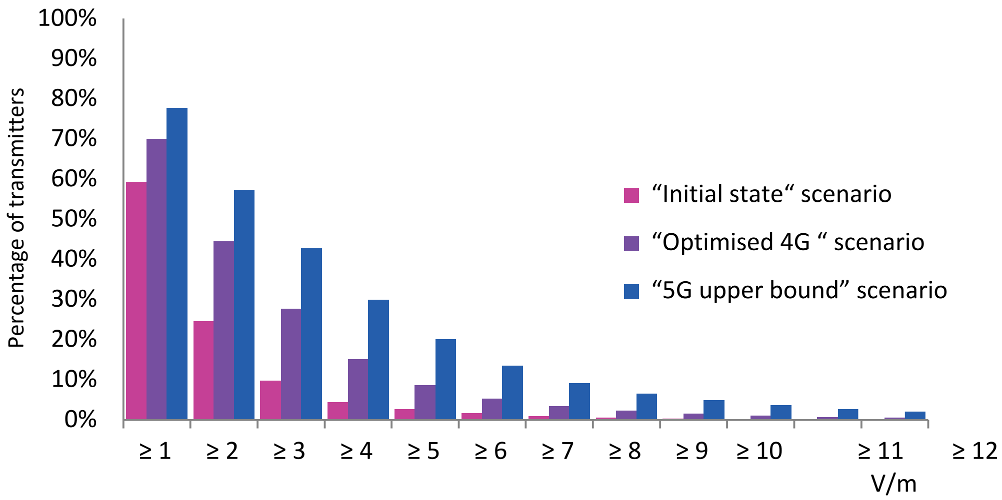

Figure 4-10: total contributor transmitter distribution behind facades (indoors)

	“Initial state” scenario	“Optimised 4G” scenario	“5G Upper bounds” scenario
Percentage of transmitters generating a point ≥ 6 V/m	1.6 %	5.2 %	13.5 %

Table 4-6: transmitters generating a point greater than or equal to 6 V/m behind facades (indoors)

In Table 4-6, one can see that the number of transmitters generating a point greater than or equal to 6 V/m increases depending on the scenario until it reaches almost one transmitter in seven in the last scenario.

4.5.2 Evolution of exposure in front of facades (outdoors)

To study the evolution in front of facades (outdoors) according to the different scenarios, the distribution of exposure is shown below with the average and the number of points that generate an exposure value greater than or equal to 6 V/m, as well as the distribution of transmitters contributing to the exposure with the percentage of transmitters generating a point for which the exposure is greater than or equal to 6 V/m.

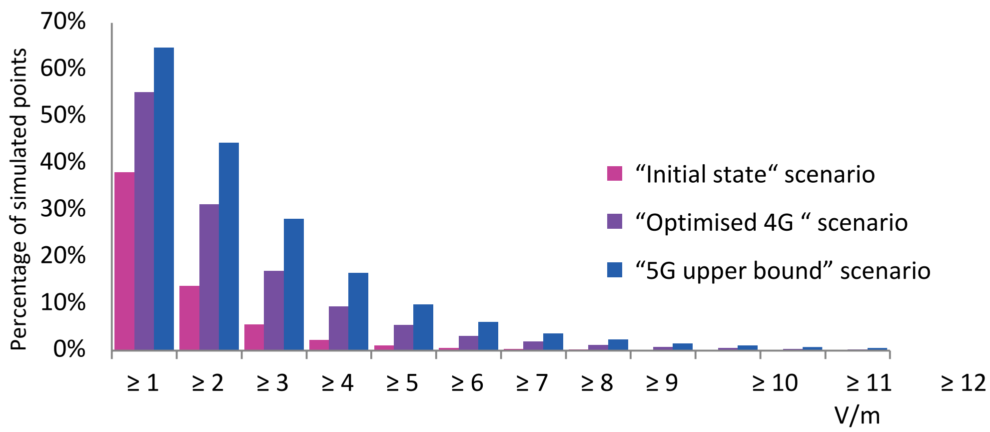

Figure 4- 11: total exposure distribution in front of facades (indoors)

	"Initial state" scenario	"Optimised 4G" scenario	"5G upper bounds" scenario
Average	1 V/m	1.7 V/m	2.3 V/m
Point>= 6 V/m	0.55 %	3.15 %	6 %

Table 4- 7: evolution of exposure in front of facades (outdoors)

Exposure increases depending on the scenario in front of facades (outdoors), the number of points greater than or equal to 6 V/m is multiplied by about 11 outdoors (see Table 4-7).

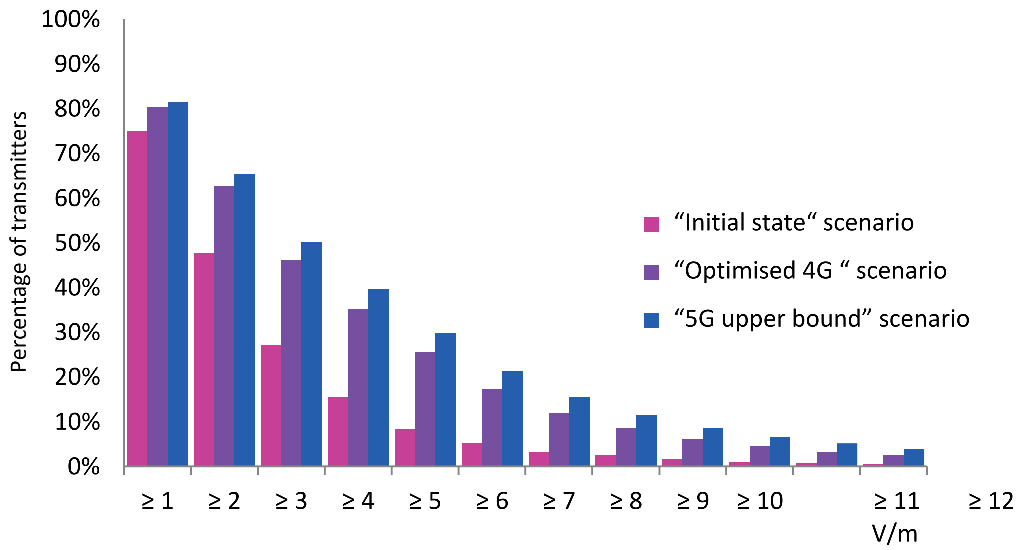

Figure 4-12: total contributor transmitter distribution in front of facades (outdoors)

	"Initial state" scenario	"Optimised 4G" scenario	"5G upper bounds" scenario
Percentage of transmitters generating a point ≥ 6 V/m	5.3 %	17.4 %	21.4 %

Table 4-8: transmitters generating a point greater than or equal to 6 V/m in front of facades (outdoors)

In Table 4-8, one can see that the number of transmitters generating a point greater than or equal to 6 V/m increases depending on the scenario until it reaches almost one transmitter in five (21.4 %) in the last "5G upper bounds" scenario.

5. Conclusions

Digital modelling made it possible to estimate the electric field exposure levels generated by mobile telephony network antennas in a very dense urban area (14^{th} district of Paris).
A digital model of the land and buildings was created, updated and validated. All the antennas and transmitters were included from information provided by the four mobile phone operators and validated by the ANFR.

The exposure levels in front of facades (outdoors) are generally higher than the exposure levels on the ground. Exposure behind facades (indoors) is highly reduced compared to outdoor exposure.

Using the assumption of an optimised 4G deployment, the average exposure level increases by about 66 % and generates six times more exposed points (levels higher than the attention value of 6 V/m). If operators were to attempt to meet the increasing volume of mobile data without 5G, 4G optimisation would therefore lead to increased exposure in the densest areas.

Using the assumption of an addition of 5G transmitters to the optimised 4G, the average exposure level increases by about 30 % and generates about 50 % additional points greater than 6 V/m.

The exposure to "5G only" created 0.2 % of points greater than or equal to 6 V/m indoors and 1.1 % outdoors. The 5G beam steering antennas in the 3.4-3.8 GHz band in the long term should not be the main contributors to exposure, including in dense urban areas where these antennas should be widely deployed.

Finally, at the intermediate stage of the study, it also appears that the growth in data volume will increase the number of points greater than 6 V/m in very dense urban areas. The number of transmitters that require an "atypical point" procedure will therefore be higher.