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# In-situ evaluation of exposure induced by 5G antennas in the 3.4–3.8 GHz band

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**Abstract.** In this paper, exposure induced in the vicinity of four pilot sites with 5G NR antennas in the 3.4–3.8 GHz band is assessed in-situ. Different manufacturers of antennas and different types of antenna are considered. Measurements are performed without any traffic, with continuous traffic in one direction and with on demand download of files. These measurements highlighted the variation in the level of exposure depending on use and led to the proposal of a new indicator to calculate the actual exposure created by 5G networks with steerable beams. This indicator results in a reduction factor that is used to assess the exposure in live conditions based on the configured maximum antenna power.

**Keywords.** 5G NR, EMF exposure, In-situ evaluation, Massive-MIMO, Beamsteering antennas.

## 1. Introduction

The key new elements of 5G New Radio, for exposure, in the new high frequency bands are steerable beam antennas to users, wider frequency bands, finer beams and alternating exposure (Time Division Duplex, TDD mode). The expected consequences are a lower level of exposure outside the beams, a higher exposure level in the beam and a shorter exposure time.

The French National Agency of Frequencies (ANFR) carried out exploratory exposure measurements during the first trials in collaboration with the operator and the antenna manufacturer in order to better understand 5G signals, to anticipate the need to update the in situ measurement protocol and to work on the definition of a new indicator. During the tests, the 5G pilots were not open to operator subscribers.

In this paper, we are focused on four trials to consider different antennas manufacturers and configurations.

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**Table 1.** List of 5G pilot sites under study

| Town/City | Manufacturer | Antenna type | Height of antenna |
|---|---|---|---|
| Mérignac | Huawei | 64T64R | 8 m |
| Nozay | Nokia | 64T64R | 40 m |
| Douai | Ericsson | 64T64R | 28 m |
| Pau | Huawei | 32T32R and 8T8R | 45 m |

## 2. Sites characteristics and measurement configuration

### 2.1. *Sites characteristics*

The sites selected for these measurements were chosen in order to cover different configurations of antennas tested in France in the 3.4–3.8 GHz band. These sites were also selected on the basis of the direct and unobstructed visibility of the antennas.

The sites that were the subject of this analysis are listed in Table 1.

The 5G NR standard defined by 3GPP [1] is very open and provides great flexibility in the choice of the many parameters that characterize the signal.

Similarly to 4G, 5G NR uses OFDMA (*orthogonal frequency division multiple access*) modulation, which is based on a division of the time/frequency matrix into elementary resources. In frequencies, the unit is the size of a sub-carrier in kHz; in time, it is the duration of an OFDM symbol in milliseconds. The OFDM symbols are grouped by 14 to form *slots*. These elementary resources are then grouped together to form frequency blocks (RB for *resource block*) containing a number of sub-carriers, one-millisecond sub-frames and ten-millisecond frames.

In the tested 3.4–3.8 GHz band, a TDD (*Time Division Duplexing*) mode is used. The split between *uplink* and *downlink* transmissions over time uses predefined frame formats. In the first cases observed in the field, this split was achieved by slot with a "DDDSU" format i.e. 3 successive D slots (reserved for downlink traffic), one S slot (for a switch shared between downlink traffic, a buffer zone without transmission and uplink traffic) and one U slot (reserved for uplink traffic). Using this configuration, the TDD ratio is about 75% in favour of the downlink. However, this first format tested in the field was not the one adopted by the French regulator Arcep in its decision No. 2019-0862 [2] on the synchronization of terrestrial networks in the 3.4–3.8 GHz band in continental France. Another format compatible with this Arcep decision was therefore also tested on certain pilots: the "DDDDDDDSUU" format which also leads to a TDD ratio of around 75% in favour of downlink.

The 5G NR antenna scans its environment to identify the users to be served using SSBs (*synchronisation signal blocks*) that occupy a bandwidth of 20 RB, i.e. 7.2 MHz in the case of the tested pilots.

Table 2 summarizes the main characteristics of the 5G signals tested on the pilots under study in this paper.

### 2.2. *Measurement configuration*

The sites were not open to users. Three types of configurations were tested:

- A—Configuration without traffic
  The base station only sent signaling, no users were connected to the network via the antenna.

**Table 2.** Main characteristics of 5G NR signals tested on the pilots under study

| Parameters | Tested 5G pilots |
|---|---|
| Bandwidth | 100 MHz |
| Spacing between sub-carriers | 30 kHz |
| Size of an RB resource block | 12 sub-carriers |
| Number of available resource blocks | 273 |
| Frame duration | 10 ms |
| Slot duration | 0.5 ms |
| Number of symbols per slot | 14 symbols |
| Frame format | DDDSU or DDDDDDDSUU |
| TDD ratio | 75% downlink |
| Signalling signal position (SSB) | Central |
| SSB periodicity | 20 ms |
| Number of SSBs | 1, 6, 7 or 8 |
| Configured maximum power | 200 W |

**Table 3.** Electric field strength measured without traffic on the sites that were the subject of supplementary measurements

| Town/City | Manufacturer | Electric field strength without traffic |
|---|---|---|
| Mérignac | Huawei | 0.1 V/m–0.2 V/m |
| Nozay | Nokia | 0.05 V/m–0.6 V/m |
| Douai | Ericsson | 0.1 V/m |
| Pau | Huawei | 0.01 V/m–0.1 V/m |

- B—Test configuration with continuous traffic in a blocked beam
  In this configuration, the base station sent a constant and continuous stream of data in a given direction. This was achieved either by using a test mode implemented in the antenna or by using a user equipment (UE) downloading continuously data. In this configuration, the beam was therefore blocked in a given direction.
- C—File transfer configuration in a blocked beam
  In this configuration, traffic was generated by on-demand download using different size files (150 MB, 500 MB, 1 GB, 10 GB).

The measurements were taken at different points at 1.5 m above the ground, outdoors, in direct view of the antenna, within an antenna beam and outside the beams. A spectrum analyzer and a suitable tri-axis antenna probe have been used. The isotropic field strengths were assessed in the channel power mode with 100 MHz bandwidth and averaged over 6 min, in compliance with French regulation.

## 3. Results

### 3.1. *Exposure levels without traffic*

The isotropic averaged electric field strength measured at distances ranging from 35 m to 200 m from the 5G antennas, in the absence of traffic, over the 100 MHz transmitter frequency band is between 0.01 V/m and 0.6 V/m (see Table 3). In absence of traffic, exposure is extremely low compared to the limits of 61 V/m in this frequency band. Signaling traffic is very limited in 5G NR.

## 3.2. *Exposure levels with full traffic in a blocked beam*

### 3.2.1. *Huawei site in Mérignac*

On this site, a 64T64R Huawei antenna (64 transmitters and 64 receivers) is installed at a height of 8 m on a tree-shaped support (see Figure 1). The user equipment (UE) is in line of sight of the antenna at about 150 m. The maximum electric field was measured at this site at about 9 V/m in the vicinity of the UE served by the antenna.

Figure 2 shows, on the left, the electric field strength measured at different distances from the 5G antenna, along the UE axis. Reflections from the ground result in constructive and destructive field combinations which explain the field strength of only 4 V/m at 120 m from the antenna and the field strength of 8.5 V/m at 90 m from the antenna.

Figure 2 shows, on the right, the beam width at 1.5 m from the ground and at a distance of 150 m from the antenna. As one moves away from the UE served by the antenna, the averaged field strength drops rapidly (by a factor of 2 at 7.5 m on either side of the UE). On one side of the UE the reflection of the field on the large building is observed, this reflection causes a field strength of 8 V/m at about 15 m from the UE compared to a little more than 1 V/m at the same distance from the UE, but on the other side, with no reflection.


**Figure 1.** Satellite view of the Mérignac measurement site with the positioning of the antenna, the UE which receive the data sent by the antenna and the measurement axis in black.

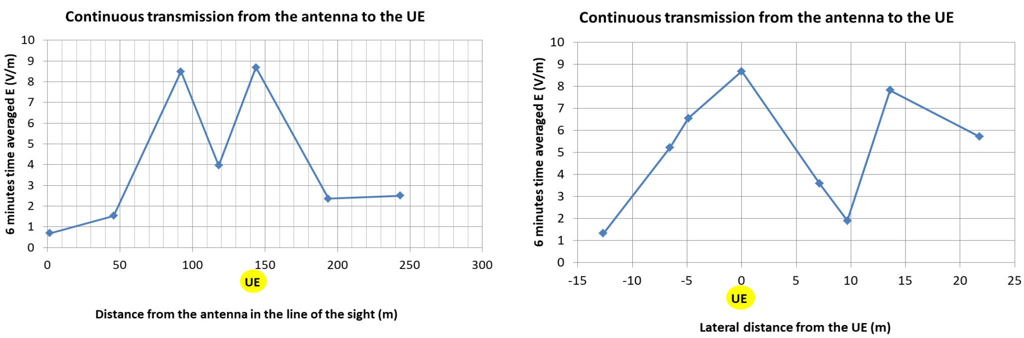


**Figure 2.** 6-min averaged field strengths measured over 100 MHz band in the antenna line-of-sight for the left figure and on the sides of UE for the right figure.

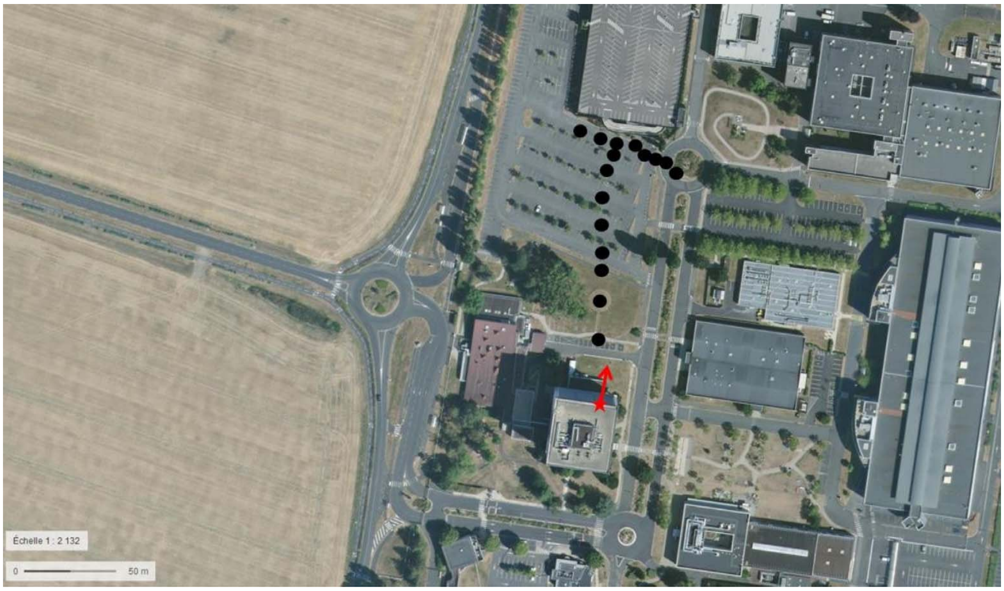


**Figure 3.** Satellite view of the Nozay site and sector no. 1 pointing towards a car park, the measurement points are shown in black. The antenna and its line of sight are shown in red.

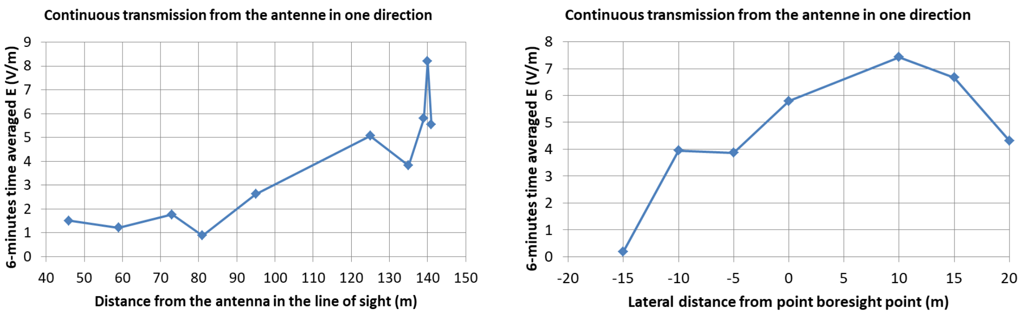


**Figure 4.** 6-min averaged electric field strengths measured at sector 1 of the Nokia site in Nozay on the left in the line of sight of the antenna and on the right perpendicular to the line of sight of the antenna at about 140 m from the antenna.

### 3.2.2. *Nokia site in Nozay*

In Nozay, two 64T64R Nokia antennas are installed on a 40 m high building. One of the antennas (sector 1) is installed on the top floor of the building at a height of 38.5 m and is directed towards a car park with a very high mechanical tilt of 18° (see Figure 3). An antenna test mode is used to send traffic continuously and with the antenna at maximum load. Considering the 18° tilt, the boresight point is at about 125 m from the antenna.

The maximum 6-min averaged field strength assessed over 100 MHz bandwidth is 6 V/m in this sector and these configurations. Figure 4 shows the field strengths measured in the line of sight of the antenna and perpendicular to it. A building located about 150 m from the antenna can explain the field variations between 130 and 140 m in the line of sight of the antenna.

The other antenna (sector 2) is installed on the roof of the building at a height of 41.5 m and is directed towards fields with a mechanical tilt of 8° (see Figure 5). The antenna test mode makes it

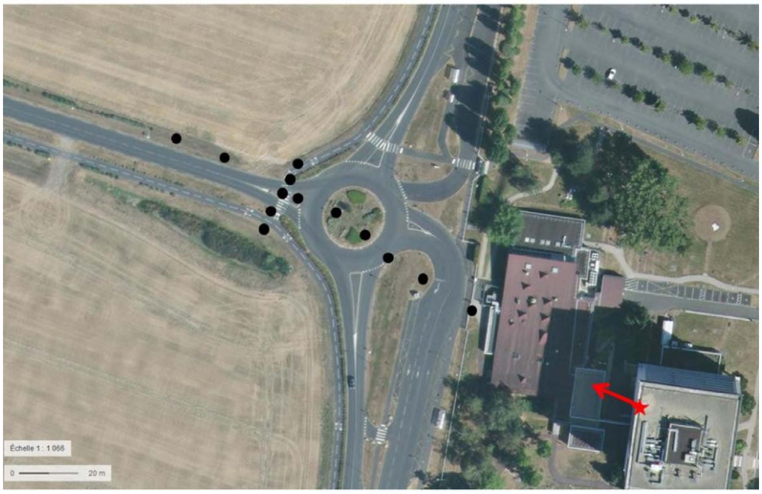


**Figure 5.** Sector 2 of Nokia's site in Nozay with an antenna installed at a height of 41.5 m (shown in red in the picture) and measuring points shown in black in the picture.

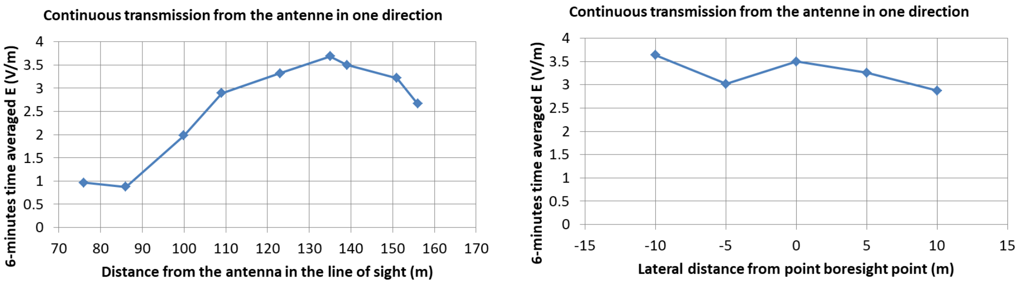


**Figure 6.** 6-min averaged electric field strengths measured at sector 4 of the Nokia site in Nozay on the left in the line of sight of the antenna and on the right perpendicular to the line of sight of the antenna at just under 140 m from the antenna.

possible for data to be transmitted in a tilted beam of 18° (8° mechanical and 10° electrical) with a boresight point at theoretically 134 m from the antenna.

The maximum 6-min averaged field strength assessed over 100 MHz bandwidth is 3.5 V/m in this sector and these configurations. This electric field strength is lower than in sector 1 because of the electrical tilt which causes gain losses. Figure 6 shows the field strengths measured in the line of sight of the antenna and perpendicular to it. Perpendicular to the main azimuth of the antenna, it was not possible to move away as far as in the other cases and the width of the beam is not identifiable.

### 3.2.3. *Ericsson site in Douai*

In Douai, the 64T64R antenna was located on a building at a height of 28 m and the measurements were taken near a terminal in a car park in direct view of the antenna and in its main line of sight (see Figure 7).

The maximum 6-min averaged field strength assessed over 100 MHz bandwidth is 1.4 V/m on this site in these configurations. The 6-min averaged field strengths measured along the axis of the antenna and at the sides of the modem are shown in Figure 8. These field strengths are lower


**Figure 7.** Satellite view of the Douai site with the antenna on a building roof, the user equipment (UE) in a car park (orange dot) and the measurement points in yellow.

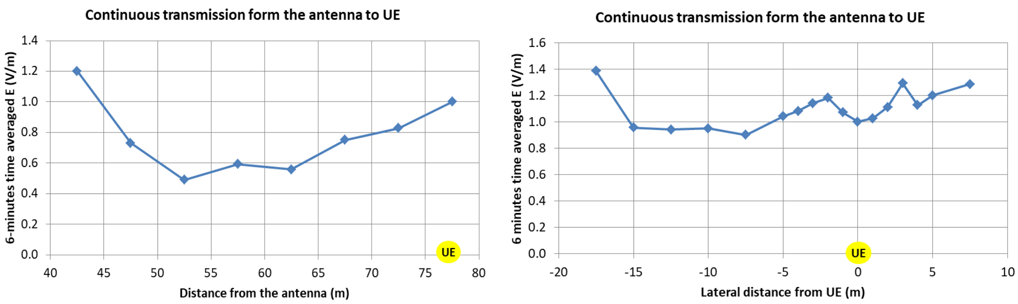


**Figure 8.** 6-min averaged field strengths measured over 100 MHz band in the antenna line-of-sight for the left figure and on the sides of UE for the right figure.

than those observed in similar conditions (such as at Nozay's site for example). These lower levels are probably due to a lower antenna steering capability and a lower level of gain in the direction of the terminal than the maximum antenna gain.

### 3.2.4. *Huawei site in Pau*

On this site, the antennas were located on a 45 m high building and traffic was continuously directed towards a UE located 125 m from the antenna, in direct view in a street at the foot of the building supporting the antennas (see Figure 9).


**Figure 9.** Satellite view of the Pau site with the antennas on a building 45 m high and the UE located 125 m from the antenna, in direct view in a street at the foot of the building supporting the antennas. The yellow and orange dots are the measuring points.

On this site, the transmission came from either a 32T32R or an 8T8R antenna. The 8T8R antenna's vertical orientation capability is much lower than that of the 32T32R antenna, which in turn is less than that of a 64T64R antenna.

The maximum field strengths averaged over 6 min and measured over 100 MHz bandwidth are 1.8 V/m in the case of the 32T32R antenna and 1 V/m in the case of the 8T8R antenna (see Figure 10). Probably neither the UE nor the measurement points were located in the direct lobe of the antenna, whether in the case of the 32T32R or the 8T8R antenna, which explains the lower field strengths than in other cases, such as in Toulouse or Mérignac for example.

### 3.3. *Exposure levels generated by on-demand downloads in a blocked beam*

In this configuration, exposure is triggered by a file download requested by the UE. Different file sizes from 150 MB to 10 GB were used. Thus there was no transmission throughout the 6 min of averaging time but only the time to transmit the files. As a reference, a measurement without traffic, i.e. without downloading, was also taken, as well as a measurement in the configuration discussed in the previous paragraph, i.e. with a continuous transmission at full antenna load in the direction of the equipment (named infinite case in the following tables).

Tables 4 and 5 summarize the field strengths measured over 6 min in the vicinity of the UE receiving the files of different sizes for the 2 sites where this configuration was processed. As it was on two different sites with two different antennas, the results are not exactly the same but the trend is the same.

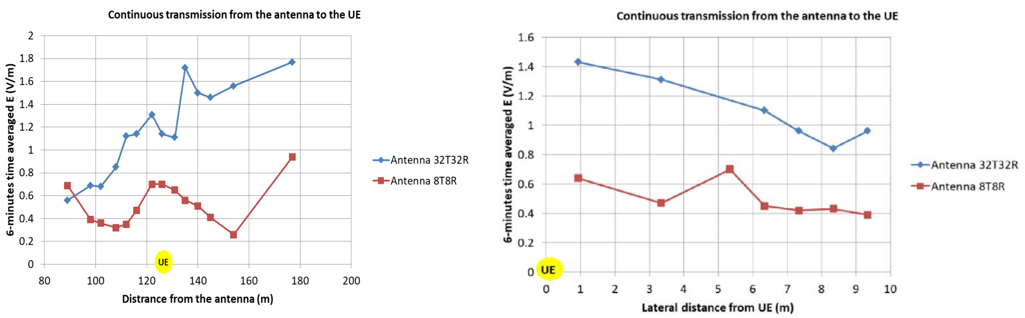


**Figure 10.** 6-min averaged field strengths measured on 100 MHz bandwidth in the antenna line-of-sight on the left and on the side of the UE on the right in the case of continuous transmission from the antenna—32T32R for the blue dots and the 8T8R antenna for the red dots.

**Table 4.** Averaged E field strengths measured over 6 min near a UE downloading files of different sizes from the Huawei site in Mérignac

| Download time | File size | Averaged E field over 6 min |
|---|---|---|
| No downloads | 0 MB | 0.2 V/m |
| 2 s | 150 MB | 0.5 V/m |
| 7 s | 500 MB | 0.8 V/m |
| 15 s | 1 GB | 1.1 V/m |
| 150 s | 10 GB | 3.9 V/m |
| Infinity | Infinity | 6.5 V/m |

The infinite case corresponds to a continuous data transmission at full antenna load to the equipment.

**Table 5.** Averaged E field strengths measured over 6 min near a UE downloading files of different sizes on the Nokia site in Nozay

| Download time | File size | Averaged E field over 6 min |
|---|---|---|
| No downloads | 0 MB | 0.28 V/m |
| 19 s | 1 GB | 1.6 V/m |
| 190 s | 10 GB | 4.8 V/m |
| Infinity | Infinity | 8.2 V/m |

The infinite case corresponds to a continuous data transmission at full antenna load to the equipment.

The exposure level is assessed over 6 min and therefore depends mainly on use. By way of comparison, a typical current monthly 4G 10 GB package could be used up in about 150 s (2 min 30 s) in the test conditions.

## 4. Exposure indicator

The measurement of exposure in the field in particular fulfils a need for information on the levels of exposure encountered on a daily basis. For legacy technologies, in the national guidelines on the presentation of simulation results published by the ANFR [3], a factor of 1.6 (i.e. 4 dB) is

**Table 6.** Estimated electric field strength at 100 m from a 5G antenna inside a building with a low power assumption and a high power assumption

| 5G | Low assumption | High assumption |
|---|---|---|
| Configured maximum power | 80 W | 200 W |
| Maximum gain | 24 dBi | 24 dBi |
| 6-min attenuation | −13.5 dB | −13.5 dB |
| Glazing | −2 dB | −2 dB |
| TDD | −1.25 dB | −1.25 dB |
| **E field estimated at 100 m** | **1.1 V/m** | **1.8 V/m** |

applied to the calculated electric field strength to account for statistical variations over 6 min for fixed beam antennas. For *indoor* use, it is supplemented by a factor of 20% (i.e. 2 dB) to take into account the attenuation by single glazing.

With 5G steered beam antennas, greater spatial and temporal variability is foreseeable. The level of exposure will indeed highly depend on the use. A new indicator is therefore proposed, based on a foreseeable use of 5G: one gigabyte of data sent in a given direction every 6 min. Assuming an average rate of 500 Mbps, the antenna will only transmit in the given direction for about 15 s out of the 6 min (about 4% of the time). This indicator for steered beam antennas has been included in the national guidelines on the presentation of simulation results of exposure to waves created by radio installations.

Assuming 8 active beams to serve the antenna coverage area, the area covered by the antenna will thus receive an average of 8 GB every 6 min, which corresponds to 960 GB per day assuming 12 h of network use per day, and 28,800 GB per month. There were 47.7 million 4G SIM cards in France at the end of 2018 and nearly 40,000 4G sites in service, which means that the average number of users per site can be estimated at 1000. Using these assumptions, the monthly 5G consumption would be 28 GB per month. By way of comparison, the averaged 4G consumption in the last quarter of 2018 was 7 GB per month on average: taking into account the fourfold increase in consumption currently observed, this volume takes into account the change in uses that seems likely to be brought about by 5G.

The assumptions used to define this indicator will be compared with the exposure measurements in the field for the 5G commercial networks and will be revised if necessary, particularly in the event of an increase in data consumption.

The interest of this indicator is that it makes it possible to assess exposure in real conditions by applying a reduction factor in relation to theoretical maximum antenna power.

For 5G, several factors will apply:

- the TDD ratio, as the antennas do not transmit continuously and provide listening ranges to receive signals from terminals: typically 75% power (i.e. 1.25 dB);
- the statistical variations over 6 min in the case of variable-beam antennas: considering the high beam mobility, which must constantly scan the entire sector covered by the antenna in order to serve the terminals located there: these are reflected by a power ratio of 4% (i.e. 13.5 dB);
- attenuation through glazing: identical to 4G, 20% in field (i.e. 2 dB).

This indicator results in a reduction factor which makes it possible to calculate the exposure in real conditions using the theoretical maximum antenna power.

The field strengths at 100 m from a 5G antenna resulting from the application of the indicator (see Table 6) appear to be comparable to those found at the same distance from a 4G antenna (see Table 7).

**Table 7.** Estimated electric field strength at 100 m from a 4G antenna inside a building with a typical current power assumption and a future power assumption

| 4G | Current | Future |
|---|---|---|
| Configured maximum power | 60 W | 160 W |
| Maximum antenna gain | 18 dBi | 18 dBi |
| 6-min attenuation | −4 dB | −4 dB |
| Glazing | −2 dB | −2 dB |
| **E field estimated at 100 m** | **1.7 V/m** | **2.8 V/m** |

However, for 4G, the reduction factor applies to the maximum antenna gain value which is only measured in the main antenna direction: outside this main direction, the field strength will be lower. On the other hand, with 5G steered beam antennas, the exposure calculated using the indicator will be valid in a higher number of directions.

## 5. Conclusion

These initial measurements considered several antenna configurations (different brands of antenna, different sizes) and different implementations of 5G NR (for example with a different number of SSBs or different frame formats).

The levels of the measured fields are all well below the regulatory limit value of 61 V/m in the 3.4–3.8 GHz frequency band.

The measurements which were carried out have confirmed that the exposure to the waves depends on many parameters, including:

- the distance between the antenna and the terminal, which is classic;
- the beam focus and the number of beams controlled by the antenna;
- the duration of presence of the beam in each direction and therefore of the data requests by the terminals in the beam.

These first measurements were carried out in special configurations allowing good control of the measurement conditions. A new indicator of exposure is proposed with a reduction factor of 13.5 dB on the maximum transmitted power to take into account the variability in time and space.

The measurements configurations were implemented in networks which were not open to the operators' customers. After the networks have been opened to the operators' customers, new measurements will make it possible to test more realistic configurations in terms of traffic and to supplement the conclusions of this paper.

## References

[1] The Mobile Broadband Standard, "3GG specification series for 5G NR", https://www.3gpp.org/DynaReport/38-series.htm.

[2] Arcep – Autorité de régulation des communications électroniques et des postes, "Decision No. 2019-0862", 2019, https://www.arcep.fr/uploads/tx_gsavis/19-0862.pdf.

[3] ANFR – national guidelines on numerical simulations, "La simulation des champs", 2019, https://www.anfr.fr/controle-des-frequences/exposition-du-public-aux-ondes/la-simulation-de-champs/.