Implications for Mobile Communications Infrastructure of Arbitrary Radio Frequency Exposure Limits

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Contents

Executive summary

Wireless communication services provide substantial social, economic and personal-safety benefits. To work efficiently mobile communication networks need sufficient infrastructure to meet the coverage and service quality expected by consumers, and often mandated by governments through licence conditions. As consumer demand increases and the range of wireless communications options expands additional infrastructure is required.

As the new 5th generation or 5G networks are introduced this demand will only increase further. 5G addresses the very large growth in data and connectivity demand as more and more devices go online and remain connected 24/7. 5G offer much faster connections, shorter response times (latency) and increased capacity, and is a key infrastructure for the Internet of Things (IoT) and innovation of emerging technologies such as autonomous vehicles, smart manufacturing and virtual reality.

The mobile communications industry encourages governments to adopt radio frequency (RF) electromagnetic field (EMF) exposure limits for mobile communications infrastructure that are based on the recommendations of the World Health Organization (WHO) and the International Telecommunications Union (ITU) . Compliance with these recommendations will provide protection for all persons against all established health risks from exposures to RF signals.

RF measurements near base station sites show that public exposures to radio signals are typically hundreds or even thousands of times below the accepted international safety recommendations.

However, public concern over the deployment of this infrastructure in some countries has led to the adoption of arbitrary restrictions, such as lower national exposure limits. These restrictions are not based on a clear scientific rationale taking into account the weight of research. Such measures provide no additional health protection for the community but they do have a real impact on efficient network deployment and operation and can adversely affect the introduction and deployment of new technologies such as 5G that would otherwise provide further economic and social benefits to the community. This paper examines the technical and public policy implications of arbitrarily lower RF exposure limits.

The key technical and network related implications of lower limits can be summarized as follows:

- **Larger compliance zones:** Without site modification, lower exposure limits result in larger compliance distances, or compliance zones, around a base station site. The compliance zones may become unrealistically large, and reach publically accessible areas;
- **Difficult site sharing:** Lower limits can adversely affect the ability of network operators to co-locate and site share, resulting in an overall increase in the numbers of base station sites and therefore greater energy use;
- **More sites needed:** Lower exposure limits limit the number of services that can be provided at any given site since the site must be designed to ensure that it remains within the limits and that the compliance zone remains manageable. In practice, lower limits therefore result in inefficient deployment and an overall increase in the number of sites required by a given operator when compared to a network deployment based on the international limits;
- **Gaps in coverage:** To ensure compliance with lower limits the power output of antennas may have to be reduced. However, such a reduction in an existing network will affect coverage and create 'gaps' in the network, which will either result in patchy service and dropped calls, or require additional base stations to be deployed to restore coverage.

- **Restricting technology innovation:** As the technology evolves, lower exposure limits restrict the feasibility of future technological innovation being introduced, as site compliance and availability as well as efficient network deployment are all key considerations.

In addition, lower exposure limits give rise to a number of policy implications for government and the broader community, namely:

- **Lack of science based rationale:** The internationally recommended exposure limits have a strong scientific basis, whereas the adoption of lower limits becomes purely an arbitrary exercise which lacks a scientific rationale;
- **Perception of less protection:** Lower exposure limits may result in very little apparent change to the measured signal level in public areas near a given site but the site may be perceived as operating at a 'higher' level because the margin between the measured level and the reduced limits is less;
- **More base station applications: In many cases lower limits will simply result in an increased number of base stations to provide equivalent service.** In view of the fact that proposals for lower limits are often discussed when there is community unease with base station deployment, imposing a policy change that results in more base stations is not likely to reassure the public, and based on experiences in other countries, most often leads to increased levels of concern.
- **Restriction on the economic and social benefits that mobile communications provides:** Lower limits inhibits the ability for cities to deploy smart technology, the building of more sustainable societies and the encouragement of start-ups and other economic enterprises that are reliant on the availability of fast, reliable and competitive mobile connections.

Finally, such proposals ignore the overall policy environment that mobile communications networks operate within:

- There is a substantial amount of scientific research that has been undertaken into the overall safety of RF. This has resulted in development of protective and internationally accepted RF exposure standards.
- Both the standards and the underlying research are subject to ongoing review.
- All products, both on the network and on the device side, are designed and tested for compliance with the standards.
- Networks are inherently efficient, minimising the output powers of both the base stations and devices to only that which is required to provide the services.
- Industry (and government) communicate openly on the issues and continue to support ongoing research to address any remaining gaps in scientific knowledge.

For the above reasons, the mobile communications industry believes that the adoption of limits below those established by ICNIRP and recommended by the WHO represents a poor policy choice without evidence of health benefits, and one that actually threatens the proven safety, security and economic benefits that mobile communications provide to the community at large.

Introduction

Wireless or mobile communication services continue to grow substantially around the world, and provide enormous benefits to our communities, our economy and to each of us individually. However, to work efficiently mobile communication networks need sufficient infrastructure to meet the coverage and service quality expected by consumers, and required by governments. As consumer demand increases and the range of wireless communications options expands additional infrastructure is required.

The infrastructure is made up of an interconnected network of antenna sites called 'base stations.' The antennas transmit the radio frequency (RF) electromagnetic fields (also called radio waves) that are fundamental for mobile communications. The intensity of the RF fields is assessed in order to guarantee compliance with existing safety standards.

Exposure standards specify the maximum RF intensity that is accepted for a person to be exposed to, which is the exposure limit. There are limits for the general public, as well as for occupational groups.[1]

The exposure standards in most countries are, as recommended by the World Health Organization (WHO) and the International Telecommunications Union (ITU), national adoptions of the guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). ICNIRP continually reviews the scientific research performed around the world into the health effects associated with exposure to RF fields. Such research has been undertaken for over 60 years, investigating a large number of frequencies, modulations and power levels to determine the possibility of adverse health effects.

ICNIRP uses the resulting body of scientific knowledge to develop appropriate recommendations for safety levels for the public as well as for occupational workers. The ICNIRP guidelines include large safety margins for the general public, and the limits have been designed to protect all members of the community including the sick, elderly and children.

RF measurements near base station sites typically show public exposures to radio waves that are hundreds or even thousands of times below the ICNIRP exposure limits.

In some countries, however, public unease about the deployment of base stations has led to calls for the adoption of lower national exposure limits. Such proposals have no scientific basis, and would provide no additional protection against any established health risks. Instead, such proposals could entail a dramatic increase in the number of base station antennas needed for maintaining a mobile communications network, increase public concern, and hinder the development of new communication services.

Some computer modelling results are included in this document in order to visualize the impact on existing and future mobile communication services of adopted or proposed lower limits. These examples compare ICNIRP's electric field strength and power density limits of 41 V/m at 900 MHz and 10 W/m^2 above 2 GHz with limits of 3 V/m and 0.6 V/m (at 900 MHz) and 0.1 W/m^2 and 1 W/m^2 above 2 GHz.[2]

RF exposure from base stations

Base station antennas transmit RF electromagnetic fields (also called radio waves or EMF). For antennas using 3G and 4G (LTE) the emission pattern is typically very narrow in the vertical direction (height) but quite broad in the horizontal direction (width). For 5G this becomes a more complex pattern because 5G also utilizes massive MIMO (multiple input, multiple output) antennas that can have many or even hundreds of antenna elements to send and receive data simultaneously. 5G also utilizes beam forming and beam steering so rather than sending the radio waves in a wide horizontal pattern, it can direct the radio signal to the user, ensuring a greater efficiency, reduced interference and higher data speeds for the user.

Irrespective of which generation of the technology in use, the RF field intensity generally decreases rapidly the greater the distance from the antenna. Further information on base stations can be found in Annex A.

1 See the publication *RF Safety at Base Station Sites,* available from our websites.

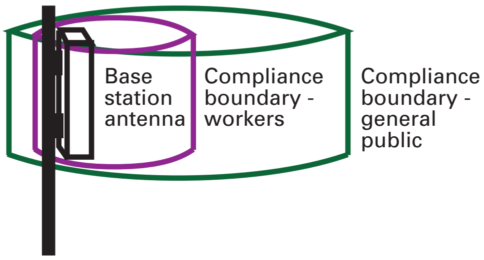
2 Note that throughout this document comparisons are made between squared electric field strength levels and squared electric field strength limits or between power density values and power density limits, since these are related to the absorbed power in the body. Therefore, 3 V/m is 0.5% (3*3/41*41), 0.6 V/m is 0.02% (0.6*0.6/41*41) and 0.1 W/m2 is 1% (0.1/10) of the recommended ICNIRP limit.

Compliance boundaries

Around each base station antenna a compliance boundary is established for workers and the public, see Figure 1. This boundary is located at the distance from the antenna where the RF field intensity coincides with the exposure limits. Inside the boundary, closest to the antenna, the RF field intensity may exceed the limits. This region is often called the compliance zone or exclusion zone, since measures must be taken to restrict people's access to this area. Since there are different exposure limits for the general public and for occupational workers, there are two compliance boundaries.

Exposure standards and compliance assessment standards applicable to base stations are discussed in Annex B. Further information about the antenna types used in base stations, and their typical compliance boundaries, can be found in Annex C.

Figure 1. Compliance boundaries of a sector antenna. The region inside the boundary is where the exposure limits may be exceeded, and thus indicates where access should be restricted.



Typical exposure levels from base stations

When a base station is being considered for construction, engineers determine the compliance boundary. This assessment is typically based on conditions that over-estimate the real exposure in actual operation, for example, by assuming that the base station is constantly operating at maximum power and that there are simultaneous connections on all available channels. All of these conditions are in reality rarely present, but taking all of them into account will ensure that the base station will be fully compliant with the relevant standards.

When a base station is in operation, it is also possible to do measurements of the RF field intensity in the vicinity of the antenna. These are called in-situ measurements, and can give a more realistic assessment of the exposure, since they are performed with the base station in normal operation rather than operating at its maximum, in terms of power and call handling.

In most cases, the evaluation of compliance is with reference to the exposure limits established by ICNIRP. These limits are expressed in electric field strength E (unit volt per metre, V/m) or power density S (unit watt per square metre, W/m^2). The limits for some typical mobile communication frequencies are listed in Table 1.

Table 1. ICNIRP exposure limits for the general public

Frequency (MHz)	E (V/m)	S (W/m^2)
900	41	4.5
1800	58	9
> 2000	61	10

Regulatory agencies from several countries have undertaken programs to measure a sample of operating base stations to confirm compliance with the exposure limits. Results from these measurement campaigns consistently show that typical RF exposure levels from base stations, in public areas, are hundreds to thousands of times below the ICNIRP limits. According to the World Health Organization (WHO):

> *Recent surveys have shown that the RF exposures from base stations range from 0.002% to 2% of the levels of international exposure guidelines, depending on a variety of factors such as the proximity to the antenna and the surrounding environment. This is lower or comparable to RF exposures from radio or television broadcast transmitters.*[3]

3 WHO Fact Sheet 304: http://www.who.int/mediacentre/factsheets/fs304/en/index.html

Figure 2. Results of an International Comparision of RF Exposure Measurements Levels from Base Stations

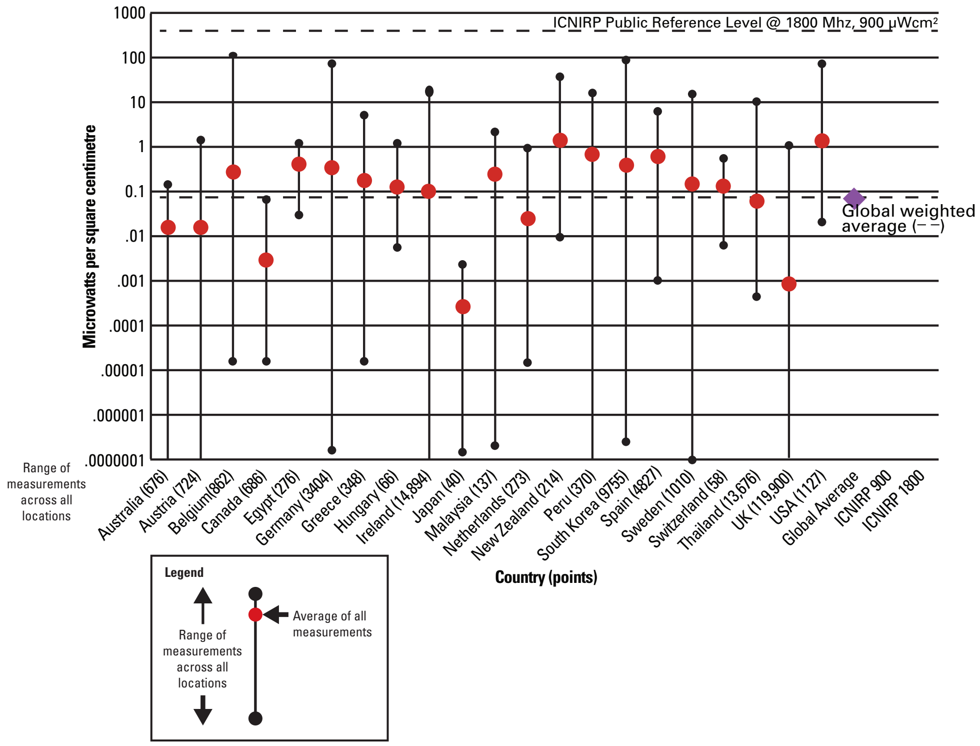


Figure 2 shows the environmental RF levels for mobile communication base station technologies based on 168,827 measurement points across 21 countries along resulting in a global weighted average of 0.073 μW/cm^2 over a decade. A later paper calculated a median environmental level for African data of 0.0185 μW/cm^2 based on 188,148 measurement points over a 7-year period which, along with the global results, are incorporated into Figure 2a. Figure 2a also includes the results of an re-analysis of 11.6 million electric field measurements undertaken by the Italian fixed RF monitoring network. The analysis of the Italian data in the mobile communications bands resulted in a mean value of 0.047 μW/cm^2.

The three values of 0.047, 0.073, and 0.0185 μW/cm^2 discussed above are consistent with each other and give confidence in concluding that irrespective of continent, country, network operator or regulatory RF exposure limit, mean environmental levels from cellular mobile communications systems are less than 0.1 μW/cm^2.

Reduced limits: practical implications for network rollout and operation

Building upon the background information presented in the preceding sections, we will now consider the impacts of adopting lower RF exposure limits for network rollout and operation.

Large compliance distances

Reduced RF exposure limits mean that the compliance distance, or compliance zone, of base station antennas when compared to those deployed under international limits is significantly larger. This means that the area around the antenna in which public access must be restricted is larger.

Figure 2a

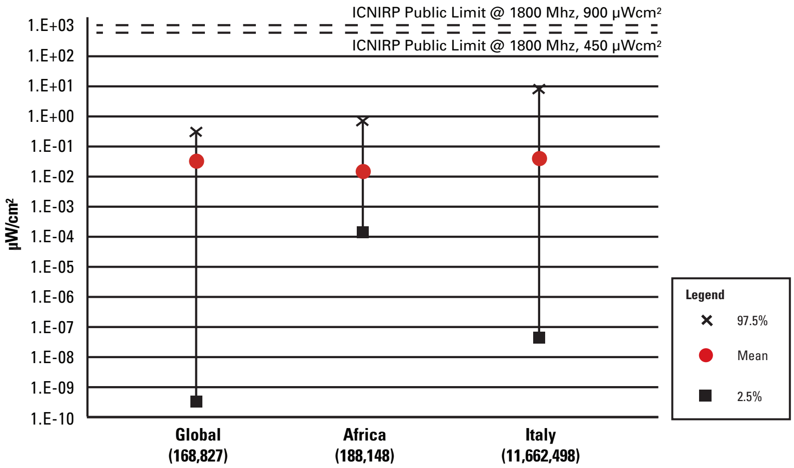


Table 2 lists calculated examples of typical compliance distance changes caused by a reduction in exposure limits.

Table 2 shows that the compliance distance for a small cell base station, typically mounted near street level, would expand from 0.5 to 15 m if the limit was reduced to 3 V/m. This means that access would need to be restricted in areas where people normally reside. For indoor base stations, which provide essential fill-in coverage inside buildings, the new compliance zone with a 1m diameter would make such deployments more difficult. For a limit of 0.6 V/m, the compliance boundary would cover the entire floor to ceiling area.

For antennas with higher output powers, the new compliance zones would also be difficult to maintain, with compliance distances from tens of metres to over a hundred metres. As a complement to Table 2, the examples shown in Figures 3, 4 and 5 visualize the compliance boundary of a 900 MHz single sector antenna on a rooftop. A comparison of the size of the compliance boundary calculated for the ICNIRP limit (Figure 3), for a 3 V/m limit (Figure 4), and for a 0.6 V/m limit (Figure 5) indicates the problem. The compliance zone expands over the adjacent buildings, and for the 0.6 V/m limit even buildings further away are affected. If the antenna had been down-tilted, which is common in order to increase the network coverage on the ground, the compliance zone might even have reached ground level implying that public access in the whole area would need to be restricted.

The only mitigation factor that can be introduced to offset these increased compliance zones is to reduce the output power of the base station antenna. For existing networks, this would result in gaps in coverage which would need to be filled with additional antenna sites – or for new deployments, it means that more antennas will needed to achieve the desired network coverage.

Table 2. Typical compliance distances at 900 MHz

Base station type	Compliance distance (m) at ICNIRP limit, 41 V/m	Compliance distance (m) at reduced limit, 3 V/m	Compliance distance (m) at reduced limit, 0.6 V/m
High mast (~100 W)	8	100	500
Low mast (~10 W)	2	30	165
Microcell (2 W)	0.5	15	75
Indoor (0.3 W)	0.1	1	7

Difficulties for co-location and site-sharing

In most countries, operators will use an existing site to locate several antennas in order to provide different services such as 3G, 4G or 5G services. In many countries different operators will also ‘site share’, that is agree to jointly provide their respective services on the one site or mast where this is technically possible and subject to commercial negotiations. In this case there may be several or many antennas located at the site.

Infrastructure sharing[4] has a number of benefits. If new antennas can be deployed on an existing site, it reduces the number of additional sites that have to be found and commissioned. For this reason, and also for energy saving and aesthetic reasons, the governments of many countries actively encourage site sharing.

Adoption of lower limits would make site sharing difficult, if not impossible to undertake. The reason is that the compliance boundaries would begin to interact with one another, making it difficult to comply with the restrictive limits. The example in Figure 6 highlights the difficulty of site sharing under an exposure limit of 3 V/m. Access would need to be restricted in areas where people normally reside, or the antennas would need to be installed on separate sites.

4 For more information see the GSMA discussion paper, *‘Infrastructure Sharing’* available here: http://www.gsmworld.com/our-work/public-policy/regulatory-affairs/investment-and-competition/infrastructure_sharing.htm

Figure 3. The compliance distance of a typical roof-mounted base station, calculated for the ICNIRP limit of 41 V/m, is 2.3 meters in the forward direction.[4]

Figure 4. The compliance distance of a typical roof-mounted base station, calculated for an exposure limit of 3 V/m, is 33 meters in the forward direction.[5]

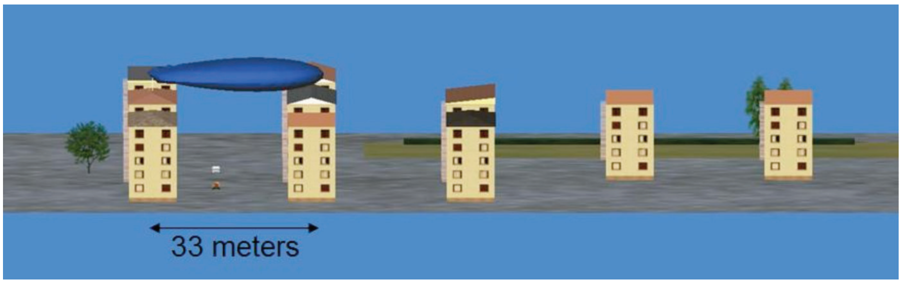
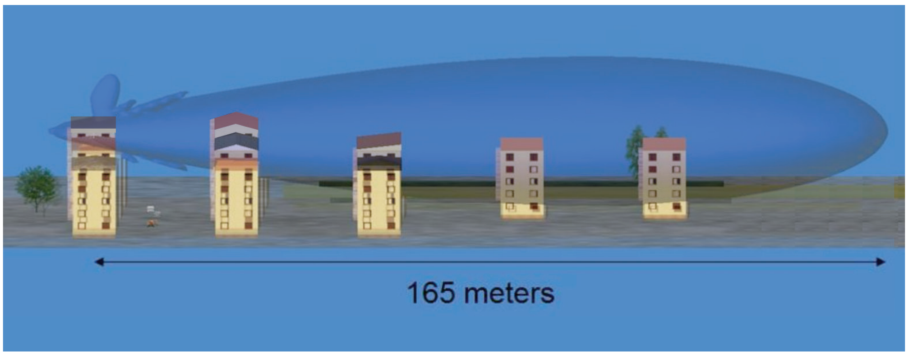


Figure 5. The compliance distance of a typical roof-mounted base station, calculated for an exposure limit of 0.6 V/m, is 165 meters in the forward direction.[5]



Impact for the provision of additional services using existing sites

In much the same way as site sharing would become a problem, operators who wish to deploy additional radio technologies or antennas at a given site would also find it difficult to ensure manageable compliance distances. Again, the compliance boundaries for each additional antenna that would be located on a site could overlap and thereby further extending the effective compliance boundary for the overall site. This may act as a barrier to the deployment of higher data rate mobile technologies such as 5G that are integral to the policies of many governments to promote access to services such as wireless internet or mobile broadband.

Reducing power output of antennas affects network coverage

Network operators faced with the above issues have only a limited range of options:

- reduce the output power of all of the antennas on a site to restore the compliance distance to a manageable area; in combination with
- deploying new services on new sites which comes with the resulting difficulties of obtaining permits and facing community opposition.

Reducing the output power of the antennas on a given site will reduce the coverage that can be provided by those antennas. The lower the limits the more the power needs to be reduced and the greater the impact there will be on network coverage, especially to coverage within buildings. Table 3 shows the power reduction needed relative to the ICNIRP limit at 900 MHz in order to maintain the same manageable size of the compliance boundaries.

5 For Figures 3, 4 and 5, the base station modeled involved a 900 MHz antenna with an output power of 10 W and antenna gain of 15 dBi.

Figure 6. Two operators share a mast with three antennas each, which at ICNIRP limits results in one separate compliance boundary for each of the six antennas (shown in aqua). When the limits are reduced to 3 V/m the compliance boundaries of the six antennas overlap resulting in one very large compliance boundary (shown as transparent blue).

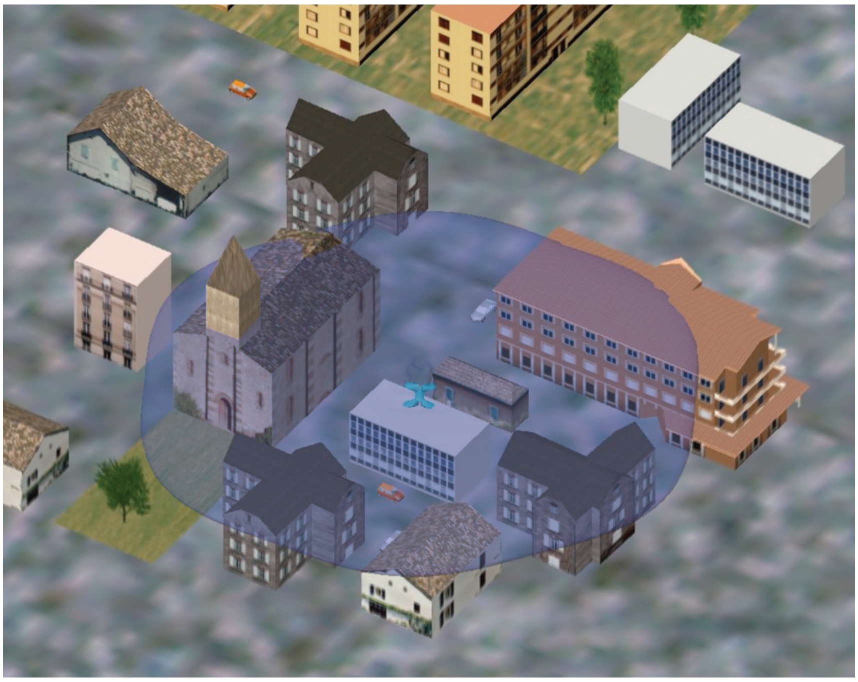


Figure 7. The orange area shows the existing indoor mobile service coverage for a commercial 3G network in suburban Sydney, Australia.

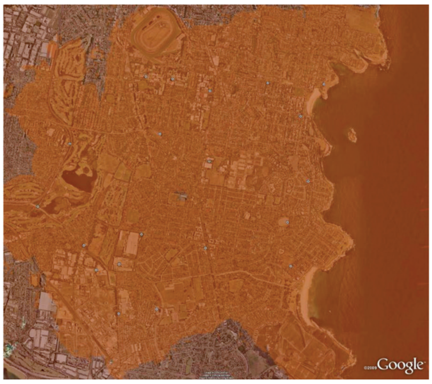


Figure 8. The orange areas are predictions of the places where indoor mobile service coverage is maintained should power reductions be imposed to meet a 3 V/m limit.

Table 3. Transmitter power relative to allowable power for ICNIRP limit

Limit (V/m)	41	14	3	0.6
Power (%)	100	12	0.5	0.02

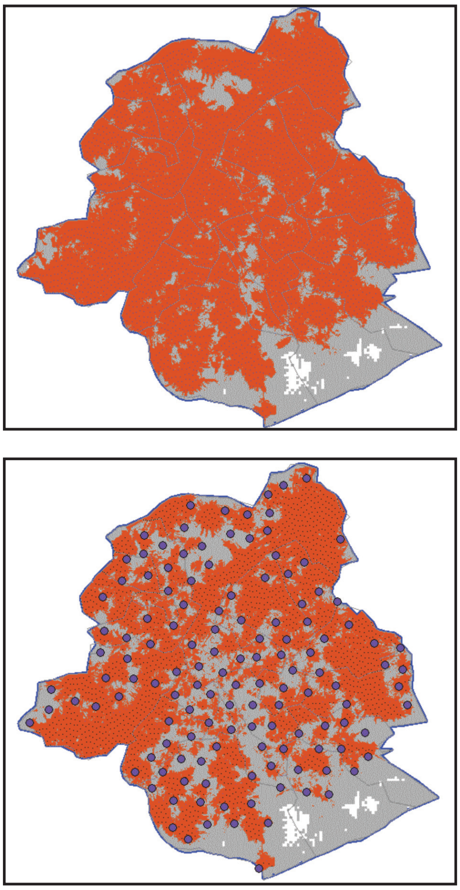
Figure 7 and Figure 8 show the impact of the power reductions needed to meet a 3 V/m limit (and maintain the same compliance boundaries) on network indoor coverage in modelling undertaken on a real network. The result is substantial gaps in the network coverage that can be provided. To address this, the operator must find new sites to deploy additional base stations to restore the mobile service that consumers expect and governments, through licence conditions, legally require.

Reducing power output of antennas results in the need for more antennas

The inevitable consequence of adopting a lower limit is that more base stations will be required to ensure that an operator can provide the required network coverage with a good quality of service.

Figure 9 illustrates the impact upon just one operator amongst the three in Belgium where a 3 V/m limit at 900 MHz has been adopted for mobile base station antennas in some regions. According to these calculations, this 3 V/m limit means that the operator is required to install 40% more base stations to restore the quality of service (QoS) to the level that can be offered when the international limit of 41 V/m is applied. While the detailed impact on each network will be slightly different, the overall consequences are the same.

Figure 9. Existing outdoor coverage areas (marked in red) (top) and post-3 V/m estimation along with the number of additional base stations required for just one operator to restore coverage to existing levels (bottom) after required power reductions to obtain manageable compliance boundaries.



Reduced limits will require more in-situ measurements

When considering the impact of adopting lower limits and retrospectively applying them to existing base stations, one immediate consequence is that the estimated maximum levels in areas where people usually reside may become very close to or even exceed the revised limits. This is especially the case when 3 V/m or lower limits are considered. In practice, this will mean that many base stations will need to have field measurements undertaken to ensure that the base station is compliant, in addition to other changes that may be required. This additional testing is expensive and unnecessary.

Cost implications

As discussed above, the number of antenna sites needed in the networks will multiply when transmitter power must be reduced. The site acquisition process is costly, not only for the operators, but also for the local administration offices. The introduction of lower exposure limits would entail a very large number of simultaneous site acquisition applications for the offices to handle. The increased costs for the operators would have to be reflected in the mobile service costs for mobile phone users. This situation is even more acute when a new network such as 5G is being deployed. The capital expenditure required by network operators to deploy their networks is already enormous and a situation that requires additional base stations may threatened the economic viability of the deployment.

Reduced limits: policy implications for government and the community

The absence of a scientific rationale

More than six decades of research into EMF and health has produced a large body of scientific literature which national and international standards organizations have reviewed to establish safe exposure limits. The WHO and the ITU recommend adoption of the ICNIRP recommendations, which already include a wide safety margin for the general public, and are designed to protect all members of the community including the sick, elderly and children.

Once the ICNIRP limits are abandoned so too is a health-based scientific rationale for any alternative limits chosen. Without a scientific justification for the limits adopted, it becomes difficult to resist calls for further reductions. This is exactly what has happened in Belgium, a country which adopted the 'precautionary' limit of 20.6 V/m (half of ICNIRP's limit at 900 MHz) in 2007, however in the face of continued pressure, since then even lower limits (e.g. 3 V/m) have been adopted in some regions. The WHO warns[6] in relation to precautionary policies:

A principle requirement is that such policies be adopted only under the condition that scientific assessments of risk and science-based exposure limits should not be undermined by the adoption of arbitrary cautionary approaches. That would occur, for example, if limit values were lowered to levels that bear no relationship to the established hazards or have inappropriate arbitrary adjustments to the limit values to account for the extent of scientific uncertainty.

6 *Electromagnetic Fields And Public Health: Cautionary Policies,* WHO Backgrounder, March 2000 available at http://www.who.int/docstore/peh-emf/publications/facts_press/EMF-Precaution.htm

ICNIRP guidelines and the national standards that have incorporated them have the benefit of decades of research to support them as well as the endorsement of the World Health Organization. Arbitrarily lower limits have no scientific justification and provide no public health benefit. As the previous sections show, however, they do have significant implications for network operators and the services that can be provided.

Reduced limits increase public concern

Often the argument advanced for the adoption of lower limits is that they are needed as a 'precaution' against possible health effects of the RF signals from base stations.

Despite the fact that the RF signals are inherently similar to those transmitted by TV and radio broadcasting towers, base stations for mobile communications are considered differently, and 'precautionary' measures are applied discriminatingly. However, there is now a growing body of research showing that adopting 'precautionary' measures such as lower limits, is having the opposite effect to that intended: it is increasing, not lowering, the level of concern amongst the general public.[7]

Reduced limits affect emergency services

One of the consequences that is often overlooked in the debate about the adoption of lower limits is the impact that these lower limits will have on the emergency service radio communications networks. Emergency services in many countries are moving toward the adoption of various digital-based radio technologies which are designed to provide greater coverage and allow additional services to be accessed by the officer on the ground. These emergency services' networks are deployed on the same basis as the mobile communications network, and therefore are impacted in exactly the same way as the mobile phone network if lower limits are adopted.

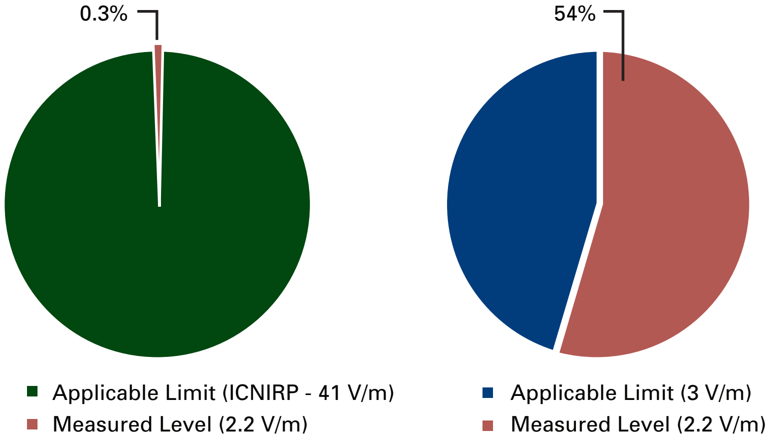
Reduced limits result in an increase in the number of base stations

As has already been discussed above, the adoption of lower limits results in a technical need for additional base stations to restore the coverage and quality of service that consumers expect and demand.

This outcome is problematic for public policy, because lower limits are most often adopted as a 'precautionary' measure which thereby gives credibility to the perception that there is something to be concerned about by living or working near to a base station. Therefore, it is not surprising that local communities are even less supportive of additional base stations in this context. Such measures risk heightened community concerns while at the same time imposing the technical and operational need on operators to deploy additional base stations.

7 Barnett *et al* 2007, Wiedemann and Schutz 2005, and Boehmert *et al* 2016

Figure 10. Measurement of exposure in public area from a base station antenna mounted on a 25m tower, viewed as percentage of 41V/m and 3 V/m limits.



Reduced limits mean base stations operating 'closer' to the limits

Again, as lower limits are most often adopted as a 'precautionary' measure, one of the difficulties this creates is the perceptual problem that exposures to base station signals are now 'higher' or 'closer' to the limits.

Figure 10 shows the results of a measurement from a base station antenna in a publicly accessible area.[8] The levels are expressed as percentages of the ICNIRP level and of the 3 V/m level after squaring the field strength values and limits.[9] The maximum exposure found corresponded to 0.3% of the ICNIRP limit. With the new restrictive limits, the exposure from their same site would be 54% of the limits without any change to the operating power or configuration of the site.

For many other base stations – especially those on smaller mounts or rooftop installations and where significant re-configuration is required to bring them within the new limits, their relative output compared to the standards is likely to be much higher.

If the decision is taken to adopt lower limits on a precautionary basis, which then results in base stations which are operating at levels not hundreds or thousands of times below the limits but rather close to them, the question that needs to be asked is how does this reassure the public?

Reduced limits restrict technology innovation

Lower exposure limits restrict the feasibility of technology innovations as site compliance, availability, as well as efficient network deployment are all key considerations. A case in point can be found in Brussels, where because of their lower limits, 5G will be extremely difficult to deploy without changes to the limits. Changes to the limits in an environment where they were taken in response to community concerns will, not surprising, be very difficult to achieve. This is despite the benefits that new technologies can offer. 5G will be more efficient in its spectrum use, provides faster and continuous connections with much lower latency (response) time to facilitate Internet of Things connections, smarter cities, schools and homes, safer vehicles and the provision of remote healthcare.

Figures 11 and 12 show the impact of lower limits on the 5G deployment. A possible 5G site on a rooftop with three 3.5 GHz base stations and one 28 GHz base station using massive MIMO antennas have been modelled. To take into account the realistic time-averaged emissions in the different directions in which the antennas can steer the beams to provide device connections, an actual maximum power of 25% of the maximum has been used. The yellow area shows the compliance boundary for the ICNIRP limit of 10 W/m^2, and the blue areas the corresponding compliance boundaries for national EMF limits of 1/10 (Figure 11 and 1/100 (Figure 12) of ICNIRP limits. Some countries, regions or cities use such low limits, and the figures clearly show that the compliance boundaries for 5G sites will be so large that the deployment will be very difficult or impossible if the limits are not changed.

Figure 11. Comparing the impact of lower National EMF limits on 5G deployment: 1/10 of ICNIRP limits. The simulation in this and Figure 13 below is based on the actual maximum power (25% of the theoretical maximum) with three sector antennas (3.5 GHz) and a one sector 28 GHz 5G MIMO base station.

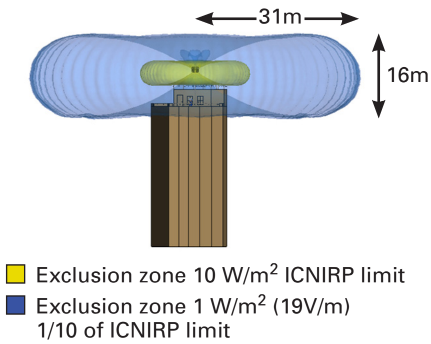
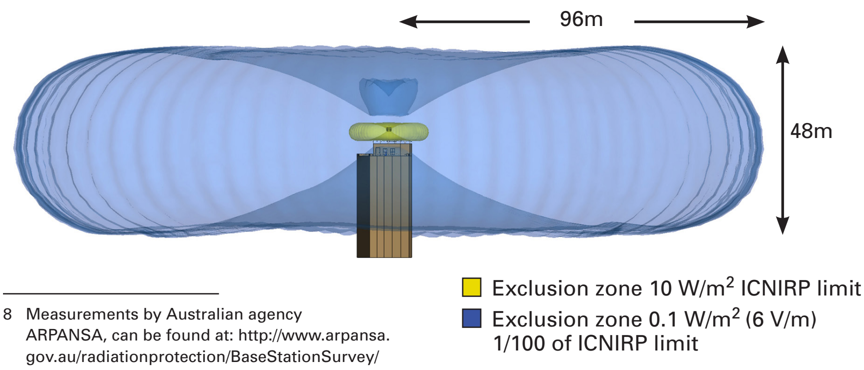


Figure 12. Comparing the impact of lower National EMF limits on 5G deployment: 1/100 of ICNIRP limits.



8 Measurements by Australian agency ARPANSA, can be found at: http://www.arpansa.gov.au/radiationprotection/BaseStationSurvey/

9 Please refer to footnote 2 for further information.

Restriction on the economic and social benefits that mobile communications provides

The ITU has estimated[10] that in the next three years 64% of mobile data traffic demands will not be served in countries, regions and even specific cities where RF-EMF limits are significantly stricter than ICNIRP. This inhibits the ability for cities to deploy smart technology, the building of more sustainable societies and the encouragement of start-ups and other economic enterprises that are reliant on the availability of fast, reliable and competitive mobile connections. A GSMA study[11] estimated that the generated 3.3% of GDP in Europe in 2017 equating to €550 billion of economic value added - which is expected to increase to €720 billion (4.1% of GDP) by 2022.

Reduced limits ignore the overall policy environment that the mobile communications industry operates within

In essence the industry operates within the following framework:

- There has been over 60 years of scientific research in the safety of electromagnetic fields involving numerous frequencies, modulations and power levels; with extensive research carried out within the last two decades specifically on mobile communications;
- The research has led to the development of exposure standards that already incorporate a substantial safety margin to provide protection for all members of the community;
- These standards are recommended by the WHO, and the expert scientific consensus is that no research has confirmed any adverse health effects caused by RF exposure at levels up to these standards;
- Products sold by the industry are designed and tested to ensure compliance with these standards;
- When operating, base stations are designed to minimise power output to avoid interference with other nearby base stations;
- Base stations also control the power output of phones, and instruct them to only use the power level needed to make and maintain a quality call;
- The industry provides communication materials on issues such as the safety of mobile phones and base stations;
- The industry itself supports ongoing research, often in partnership with other stakeholders; and
- Individual measures are available to reduce exposure from mobile phones if desired.

It is interesting to note that many of these elements – supporting research, developing standards and communicating on the issue are often called for in adopting precautionary measures in other domains. We encourage policy makers to include all of these elements as part of the efforts to address this issue.

10 International Telecommunications Union, ITU-T K. Sup 14: The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment. (2018)

11 Mobile Economy Europe 2018, GSMA, https://www.gsma.com/mobileeconomy/europe/

Conclusions

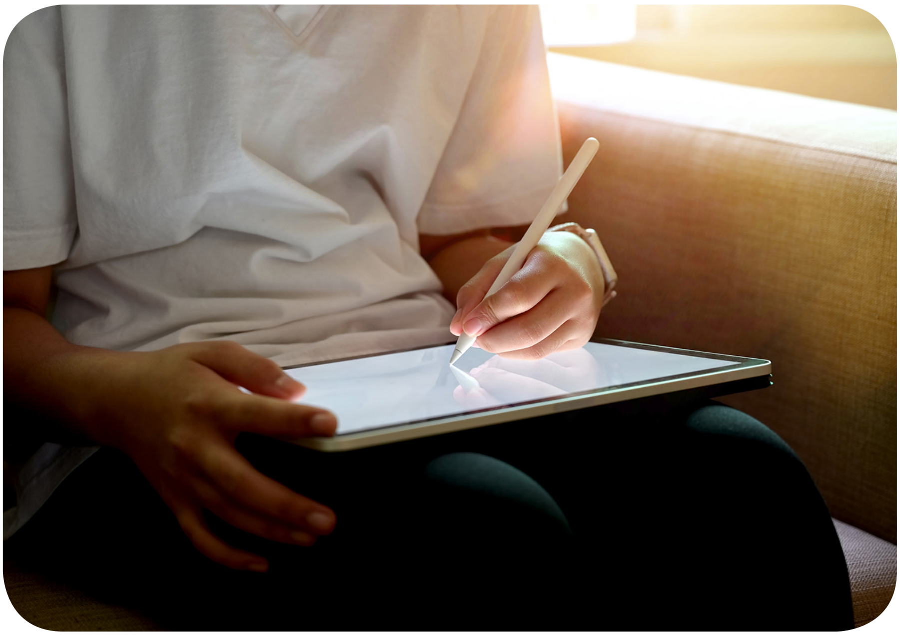
Adoption of lower limits is often seen as a politically attractive option in order to respond to the concerns expressed by some members of the community. There are a number of important policy related implications associated with such a measure, such as:

- Lower limits lack any scientific justification, and as such, resisting calls for further reductions becomes a matter of political will rather than of scientific merit;
- Reducing limits is interpreted by the public as evidence that there is something to be concerned about regarding the safety of base stations;
- Lower limits create the perception that base station emissions are now much higher when viewed as a percentage of the relevant limit compared with the international limit;
- Lower limits restrict the economic and social benefits that mobile communications provides;
- Lower limits ignore the overall policy environment that mobile communications networks operate within, which are themselves consistent with a 'precautionary approach'; and
- Consistent international experience is that 'precautionary measures' such as reduced limits only increases the level of concern within the public rather than reduce it.

In addition, such a measure is generally undertaken without considering the technical impacts that such a decision would make, namely that:

- Compliance distances become too large to be practical, and require substantial network re-design and power reductions to restore such distances to manageable levels;
- Co-location, site sharing and deploying additional services are made increasingly difficult as lower limits are adopted, necessitating more sites;
- Reduced limits restrict technological innovation;
- Requiring network operators to reduce the power output of antennas adversely effects network coverage, necessitating additional base stations to fill gaps created by reduced power outputs of nearby base stations; and
- Reductions in network coverage can adversely impact the emergency services as well as consumers who are in an emergency situation and who are relying on their mobile phone to contact emergency services.

For the above reasons, the mobile communications industry believes that the adoption of lower limits below those established by ICNIRP and recommended by the WHO represents a poor policy choice, and one that actually threatens the proven safety, security and economic benefits that mobile communications provides to the community at large.



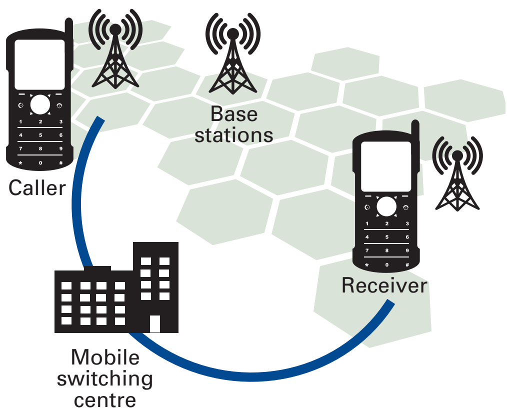
ANNEX A

General network operation and design principles

Base stations

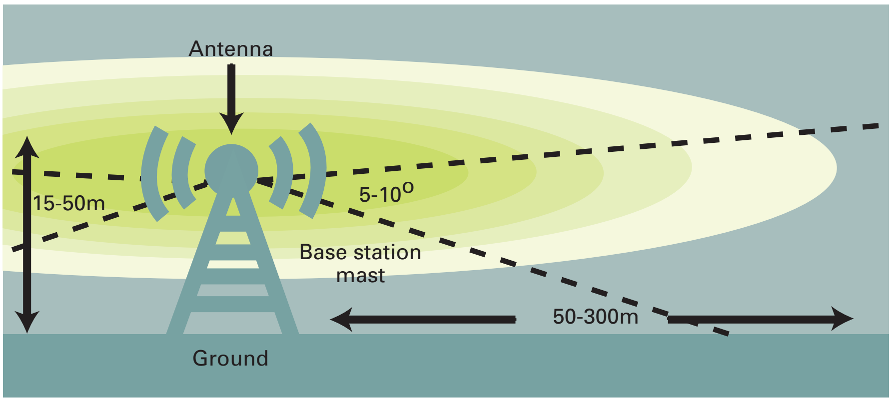
Mobile networks are made up of an interconnected series of antenna sites called 'base stations.' Base station transmitter power levels may vary considerably, depending on the size of the region, or cell, that it is designed to service.

How mobile networks work



Typically transmitted power from an outdoor base station may range from a few watts (W) to 100 W or more. However, when compared with the output from a FM radio transmitter (typically 2000 W) or TV transmitter (typically 40000 W), the base station power outputs are significantly lower. The output power of indoor base stations is even lower and similar to that of a mobile phone.

Traditional base station antennas used in 2G, 3G and 4G networks are typically about 15-30 cm in width and up to a few metres in length, depending on the frequency of operation. They are usually mounted on buildings or towers at a height of 15 to 50 metres above the ground.



These antennas transmit Radio Frequency (RF) electromagnetic fields (also called radio waves) in patterns that are typically very narrow in the vertical direction (height) but quite broad in the horizontal direction (width). Because of the narrow vertical spread of the beam, the RF field intensity at the ground directly below the antenna is very low. The RF field intensity on the ground increases slightly as one moves away from the base station and then decreases at greater distances from the antenna.

For a few meters, directly in front of the centre of the antenna, the RF fields may exceed the permitted exposure levels. In order for the public to be prevented from entering areas where the permitted exposure levels may be exceeded, the antennas are elevated, and when necessary fences, locked doors, or other means of restricting access (with appropriate signs if needed) may be implemented.

Directivity of base station antennas

Traditional base station antennas are designed to transmit the radio signals in a reasonably flat beam to optimise coverage. Antennas have 'directivity', that is to say that the transmitted energy is directed towards areas where people use mobile devices so as to maximize coverage with the lowest possible output power.

At ground level the maximum measured RF-EMF exposure is generally a small fraction of the exposure limit and will typically occur at distances between 50 and 300 m from the base station. The distance is dependent on characteristics of the site such as the antenna, the height and surrounding buildings and the surrounding terrain.

In general, base station antennas direct their power outwards, and do not transmit a significant amount from their back surfaces or towards the top or bottom, so exposures are lower in those directions. This is particularly relevant as there is a public perception that exposure is stronger directly under antennas. Therefore, when antennas are mounted on buildings, the exposures in rooms directly below the antennas are lower than in the area in front of the antenna.

Mobile phones on the other hand have antennas that are almost equally effective in all directions to ensure reception, regardless of the phone's position.

Whatever the equipment, the strength of a radio wave (called power density) decreases dramatically as it travels away from the antenna. In free space, the power density decreases to one fourth when the distance is doubled. In reality, the power density levels reduce much quicker than that due to obstacles such as, trees, buildings, etc.

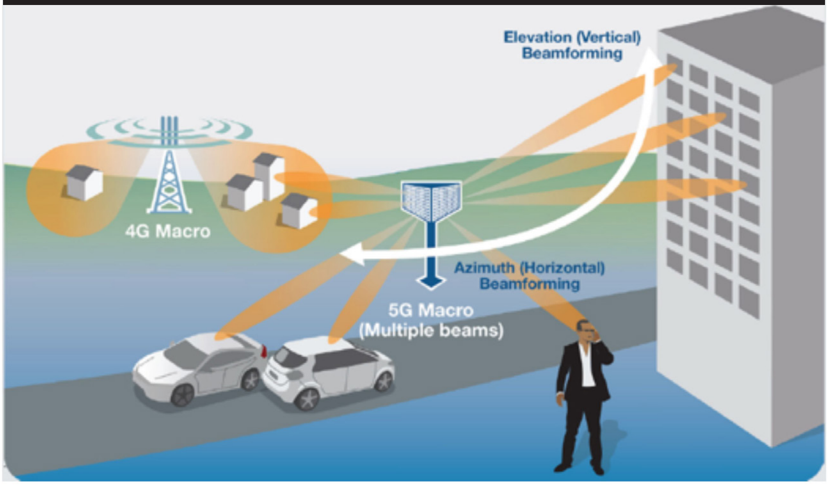
Although it may be considered desirable that base station equipment is placed in industrial areas or areas remote from habitation there has to be a balance. Equipment placed too far from the users not only gives poor communication quality but also cause the phones to increase their output power to sustain the connection, thus decreasing battery life and talk time.[12] Also, each base station can only support a limited number of simultaneous calls. As the number of subscribers grows more base stations are needed and these need to be close to where people want to use their phones.

Beam forming and beam steering (massive MIMO)

5G base stations use antennas that are different from traditional base station antennas. The new technology used is called 'massive MIMO' and the 5G antennas consist of a large number of antenna elements, typically 64 but can be several hundred, which are making it possible to form and steer beams toward connected user devices, enable very high data throughput, and serve several connected devices simultaneously. This 'beam steering' technology allows the base station antennas to direct the radio signal to the users and devices rather than in a broad pattern. It uses advanced signal processing algorithms to determine the best path for the radio signal to reach the user. This increases efficiency as it reduces interference.

The overall physical size of the 5G antennas, which are normally integrated in the base station radio unit, will be similar to conventional antennas. However for higher frequency bands (mmW), the individual antenna element size is smaller allowing smaller antenna sizes or more antenna elements (in excess of 100) in the same physical case.

Beamforming (massive MIMO)



Site design considerations

During the last decade the design of mobile communications equipment has developed significantly, with a general trend to smaller, more efficient equipment offering equal or greater functionality.

Creative antenna and mast design is capable of significantly reducing the visual profile of mobile communications infrastructure. This has proven to be a popular approach especially where the base station will be located in an aesthetically or environmentally sensitive area. It is not suitable in all locations because there may be some reduction in technical performance when using smaller antennas. In addition, some community groups have criticized mobile network operators for 'hiding' antennas.

This is not always possible for base station antennas as radio engineers can achieve optimum performance when antennas are mounted on high structures (or the top of buildings) away from physical obstruction such as other buildings and trees.

12 Note that phones are tested and certified at maximum power so regardless of the distance from the base station or level of reception the handset complies with the ICNIRP or relevant national limits.

Mobile phones

When a mobile phone is switched on, it listens for specific control signals from nearby base stations. When it has found the most suitable (usually the nearest) base station in the network to which it subscribes, it initiates a connection. The phone will then remain dormant, just occasionally updating with the network with information such as location, until the user wishes to make a call or is called.

Mobile phones use Adaptive Power Control as a means of reducing the transmitted power to the minimum possible whilst maintaining good call quality. This reduces interference between mobile phone calls and also prolongs battery life and, hence, extends talk time. The output power of mobile phones is very low. During a call, and depending on which handset is used, the output power can vary between a minimum level of less than 1 μW up to a peak level of 2 W. The maximum average power of a handset is however less than 0.25 W.

The area served by a base station is termed a 'cell'. When the caller moves from one cell to another, the system hands over the call from one base station to another seamlessly, so the caller is unaware of the change of base station and the associated output power fluctuations caused by moving either closer to or further from a base station.

ANNEX B

Existing standards for assuring compliance

There are two types of standards that are applicable to base stations: the first is the exposure standards that specify the RF-EMF exposure limits for the general public and occupational users or workers. The second types of standards are the compliance assessment standards, which are used to assess and demonstrate that a particular piece of base station equipment, or a base station site, is compliant with the exposure standards.

Exposure standards set safety limits for the public and workers that are intended to provide protection against all established health hazards. They usually provide basic restrictions, the maximum allowable RF-EMF energy deposited in the body, and reference levels, external field levels that are more easily measured for compliance purposes. The measure of absorbed radio frequency energy is Specific Absorption Rate (SAR) in units of watts per kilogram (W/kg). SAR is used below 6 GHz and above that the measure changes to Power Density, in unit W/m^2, since the absorption radio waves at higher frequencies is so superficial that SAR is no longer the best metric to be used to demonstrate compliance.

Compliance assessment standards describe the procedures used to ensure that mobile phones and base stations comply with the exposure standards.

In order to verify that the RF exposure from radio base stations is below prescribed limits standardized test protocols are used. Such standards have been developed or are under development by the International Electrotechnical Commission (IEC), the International Telecommunications Union (ITU), European Committee for Electrotechnical Standardization (CENELEC) and the Institute of Electrical and Electronics Engineers (IEEE).

Most countries around the world require or recognize RF exposure limits based on guidelines established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Both the World Health Organization (WHO) and the International Telecommunications Union (ITU)[13] recommend the adoption of ICNIRP guidelines as national exposure standards.

The IEC has published an international standard (IEC 62232) related to RF-EMF compliance assessments of base stations. Using the protocols specified in this standards, manufacturers can determine the appropriate RF exposure compliance boundaries (safety distances) around antennas for typical base station configurations at the maximum output power. The standard also covers the demonstration of compliance of base stations when the network operator puts these into service, and specifies procedures to be used to determine whether the environment (reflections and/or other RF sources) has an effect on the compliance boundary. Investigations (in some case measurements) have to be performed around the antenna out to a range where the field strength level is below 5% of the relevant exposure limit. In addition to this, the IEC 62232 includes methodology for in situ measurements that can be used for surveillance of compliance with the RF exposure limits in any location, including places where people live and work.

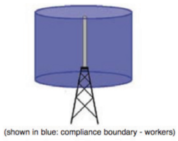
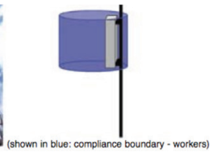
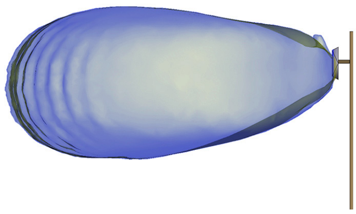
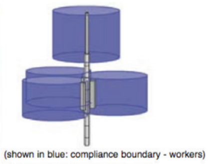
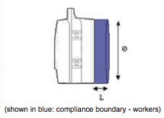
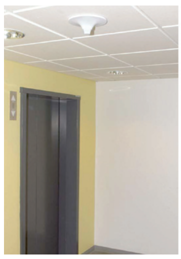
13 http://www.itu.int/itudoc/itu-t/aap/sg5aap/history/k52/k52.html

ANNEX C

Typical compliance distances for different base station antenna types

Table 4 shows types of antennas commonly found at base station or antenna sites. A photo is given of each antenna(s) as well as a sketch indicating the shape of the compliance boundary. The typical compliance boundaries given are valid for ICNIRP exposure limits.

Table 4. Base station antenna types

Omni-directional antenna Radiates RF energy equally in all horizontal directions. Output power is typically 10 – 100 watts, and the typical compliance boundary for the public is 0.5 – 5 meters from the antenna.	 
Sector antenna Restricts most of its radiated RF energy to a narrow angular sector in the forward direction. Antenna output power is typically 10 – 200 watts, and the compliance boundary for the public may then extend 1 – 20 meters from the front face of the antenna.	 
Array antenna (massive MIMO) Steers the RF energy in narrow beams to optimize the transmission between the base station and connected devices. Normally integrated in the base station radio unit. Antenna output power varies with type and frequency band, and may be around a few watts or less for mmW 5G frequency bands, and 20 – 200 watts for frequency bands between 2 and 6 GHz. The compliance boundary may extend up to a few meter for high-band low-power radios and 5 – 20 meter for the base stations operating in the lower bands.	
Antenna farms (or clusters) Antennas are often grouped together on masts. The combination illustrated here is that of an omni-directional antenna mounted above a cluster of three sector antennas. The compliance distance may be larger than for the individual antennas.	 
Radio relay antenna (or fixed point-to-point link) Concentrates its RF energy into a narrow beam in the forward direction. Power levels are typically low, less than 1 watt, and safety distances a couple of centimeters. The parabolic dish antenna is one example.	 
Micro cell antenna Typically a small sector antenna with output power of a few watts for providing coverage over short distances (typically 300-1000 meters). It is often mounted on an existing building, where it can be disguised as building features. The compliance boundary has the same shape as for a sector antenna and typically extends 0.2 - 2 meter from the antenna.	
Indoor antenna Also sometimes termed picocells and provide localised coverage inside buildings where coverage is poor or where there are a high number of users such as airport terminals, train stations or shopping centres. The power level is similar to that of a mobile phone. The compliance boundary is located within a few centimeters of the antenna.	

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