

# Wireless networks and EMF—paving the way for low-EMF networks of the future: the LEXNET project

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*While according to the World Health Organization no adverse health effects of RF-EMF have been established to date, EMF exposure from wireless communication networks is nonetheless often cited as a major cause of public concern and is frequently given considerable media coverage. This paper presents the results of a new survey on RF-EMF exposure risk perception together with a comprehensive overview of the EMF footprint of existing and emerging networks. Building on these findings we then put forward the rationale for EMF-aware networking. Subsequently, we highlight the gaps in existing systems which impede EMF-aware networking and outline the key concepts of the recently launched EU FP7 Integrated Project “LEXNET”: a new, all-encompassing, population-based metric of exposure and ways it can be used for low-EMF, QoS-aware network optimisation.*

## Introduction

Wireless networks traffic has experienced unparalleled growth in recent years, and this trend is expected to continue: users are increasingly reliant on pervasive wireless connectivity, and the amount of data shared wirelessly is forecast to grow exponentially, with a steadily varying type of content. This will be compounded by the proliferation of the machine-to-machine communication and cloud computing paradigms, which will see the connection of tens of billions of objects to the Internet over the next 10 years, much of it wirelessly. Measures to meet the growing demand, such as traffic offloading, mean that wireless small cells will become omnipresent. While this enables user devices to transmit at lower power, it also moves the transmitters closer to the user. Moreover, dedicated wireless systems will emerge to carry new services, thereby contributing to the increase in transmitter sites, especially in urban environments. Such increase in the density of all the radio connected objects and their proximity to users reinforce the public concern about RF-EMF exposure [1] even if this rising number of RF sources does not necessarily lead to an increase in exposure.

Stringent regulations exist that protect users from RF-EMF exposure [2]. To test compliance with respect to these

regulations, evaluation procedures have been standardized. However, these compliance tests are based on worst-case assumptions (i.e. maximum power emitted), and are not necessarily representative of day-to-day network functioning and management.

European Union has specifically addressed the need for low-EMF technologies in its Seventh Framework Programme (FP7, ICT Call 8), by designating low-EMF system designs as a target outcome. This target outcome recognises that there is a clear need for new network topologies and management which reduce the EMF levels without compromising the user's Quality of Service (QoS). In response to this need, 17 leading telecommunications operators, manufacturers, research centres and academic institutions have launched the LEXNET (Low EMF Exposure Future Networks) project [3], a research endeavour which aims to pave the way for low-EMF networks of the future.

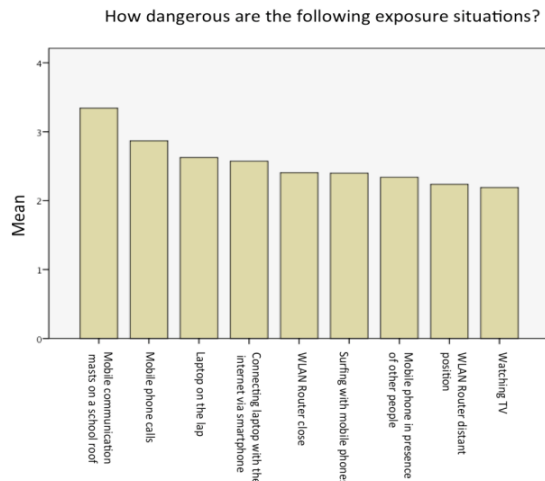
In this paper we start by discussing the user perception of exposure to RF-EMF and shed new light on this issue by presenting preliminary results of LEXNET-devised surveys. This is followed with a look at existing EMF regulations and metrics, which serves to highlight the fact that EMF exposure is not commonly one of the network management key performance indicators (KPIs). We then present one of the key concepts of LEXNET—population exposure due to both personal devices and network transmitters—and how networks could be designed with a view to minimising this exposure and in line with the pervasive trend towards human-centric computing and networks. The sections that follow look at a variety of commonly used radio access technologies (RATs), the ways in which they are managed, and how their deployment and management impact the EMF levels. And lastly, we present concluding remarks and outline the key goals of LEXNET.

## User perception of exposure to RF-EMF

The number of mobile phone subscriptions has exceeded the total population count in the developed world since 2007 and the ratio is nearing 90% in the developing world [4]. Smartphones and tablets have made popular a multitude of new

applications. Even during data sessions, the mobile is not only receiving data but also transmitting intermittently. However, from the exposure point of view, the voice calls are still an important contributor, due to the small distance of the device to the body (head) and due to the continuous emissions from the phone during a voice call compared to the only intermittent transmission during a data session [5].

As the Eurobarometer Study [1] indicates, public concern about EMF exposure is quite stable: an astonishing 46% of Europeans are still concerned or very concerned about EMF



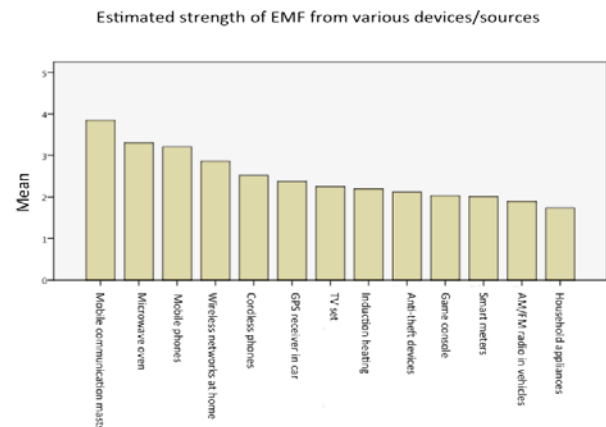
**Figure 1** How dangerous are the following exposure situations? (5-point Likert Scale: 1= not dangerous, 5 = very dangerous)

From this brief consideration, three important questions emerge: (1) What are the different sources of exposure? (2) Which factors determine the strength of exposure in the eyes of the public? and (3) How do people link exposure to risk? In order to study these issues we conducted an in-depth survey and we report here some of its key findings. Data was collected from April to May 2013 in France, Germany, Portugal and Spain, using an online survey tool. A total of 1978 respondents participated in this survey (mean age: 36 years; gender distribution: 60% female, 40% male).

The first part of the survey focussed on the perceived sources of daily RF-EMF exposure of the respondents. Additionally, we were interested in the factors which determine, in their view, the degree of EMF exposure. Another part of the survey regarded risk perception and health concerns. We report here only selected findings of our survey.

Regarding the perceived health hazards of various usage scenarios, our respondents evaluated base stations on a school roof as most dangerous (see Figure 1). On a 5-point Likert scale (1= not dangerous, 5 = very dangerous), the mean score of base station is 3.35. Using mobile phone for calls is

health risks, without however distinguishing between various sources of EMF (e.g. access points vs. hand-held devices) and their relative contribution to the overall exposure. The approach for dealing with these concerns depends on the question of whether they are justified in the light of scientific evidence. In other words, do people worry about the right thing? However, even when some public concerns are supported by science, their weight depends (or should depend) on the specific exposure situation and the magnitude of exposure.



**Figure 2** Perceived strength of EMF from various devices/sources (5-point Likert scale: 1= very low intensity 5= very high intensity).

perceived as less dangerous, averaging a mean of 2.87; a somewhat lower score characterizes the laptop used on the lap. Here, the mean danger perception is 2.63.

This finding is consistent with the perception of exposure strength due to various EMF sources (given in Figure 2). The respondents had to evaluate them on a 5-point Likert scale. Figure 2 clearly indicates that base stations are seen as the strongest EMF exposure source ("Mobile communication masts" with the mean of 3.86; followed by "Microwave ovens", mean=3.31; and "Mobile phones", mean=3.21).

Finally, a regression analysis of various exposure scenarios on health concerns demonstrates that the distance to the exposure source is not a significant predictor of these concerns, as evidenced by the values of regression coefficients given in Table 1. Significant predictors are shown to be the number of the exposure sources, the duration of the exposure, and the frequency of exposure.

Regression parameters	Distance to the source	Number of exposure sources	Duration of exposure	Frequency of exposure
$\beta$	0.013	0.098	0.104	0.074
$p$	0.680	0.000	0.002	0.014

**Table 1** Values of the regression parameters for the significant predictors.  $\beta$  represents the relative importance of the predictor variable (various exposure scenarios) in predicting the dependent variable (resulting health concerns); maximum  $\beta$  is 1.  $p$  represents the significance level;  $p \leq 0,05$  = sign.,  $p \leq 0,01$  = high sign.,  $p \leq 0,001$  = highly sign.

The above results indicate that risk perceptions of the general public and the underlying health concerns are guided by subjective models of EMF impact, which underestimate near-field exposure and overestimate far-field exposure. People are more concerned about base stations than about all other RF-EMF sources. This distortion may explain why the exposure incurred by personal EMF emitting devices such as laptops and cell phones is not a key factor in public risk perception.

### Standards and regulations on EMF

International authorities, standardization bodies, and mobile industry have jointly cooperated in the last decades on elaborating regulations that limit the human exposure to EMF and permit wireless technologies to be fully integrated in today's society. The World Health Organisation (WHO) and International Telecommunication Union (ITU) have endorsed the International Commission on Non-Ionising Radiation Protection (ICNIRP) to develop the international EMF exposure guidelines.

Accordingly, exposure standards in most countries are national implementations of the guidelines set by ICNIRP. In Europe these ICNIRP guidelines have been endorsed by EU recommendations [6]. ICNIRP uses the resulting body of scientific knowledge to develop appropriate recommendations for safety levels of exposure for the general public, as well as for occupational exposure. These guidelines define frequency-dependent maximum permitted levels of exposure for whole or parts of the body from any number or type of EMF emitting devices, including mobile phones and base stations.

Moreover, compliance standards describe test protocols that have to be carried out to ensure that wireless networks are compliant with the recommended limits. Such tests have been standardized or are under development by the International Electrotechnical Commission (IEC), the European Committee for Electrotechnical Standardization (CENELEC), and the Institute of Electrical and Electronics Engineers (IEEE). Using the protocols specified in these standards, regulatory bodies can determine the EMF exposure due to an installation or a product, e.g. identify the compliance boundary around a base station antenna or perform phantom measurement for assessing mobile phones.

However, a wide range of measurement conditions exist, such as near- or far-field exposure, short- or long-term

exposure, and exposure due to individual or multiple sources. Furthermore, the different characteristics of EMF (like frequency, intensity, and duration of exposure) result in a large number of exposure metrics, which we classify here in the following manner:

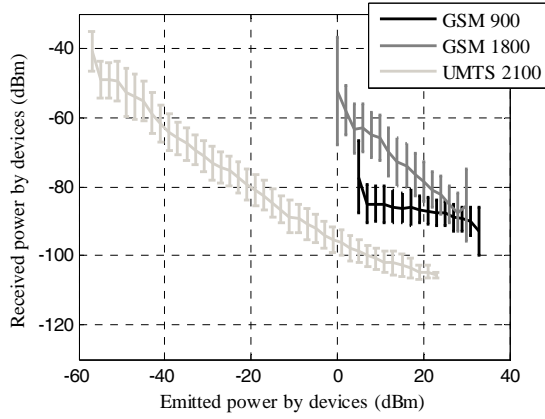
1. Incident field metrics, such as electric field, magnetic field, and power density;
2. Exposure ratios, which measure the exposure due to a single wireless communication technology with respect to the relevant limit (or alternatively based on contribution of each source to the total exposure);
3. Absorption metrics, which measure the rate at which electromagnetic energy is absorbed by the human body, i.e. the Specific Absorption Rate (SAR);
4. Dose metrics, which adjust any of the above metrics by taking into account the exposure time.

Despite the considerable amount of research in the field, current standards and metrics are built to either specifically measure the compliance of a given device or to evaluate the exposure at a specific location in a given system, which operates at a maximum power level. Typically, compliance concerning either maximal 10g-SAR for near-field sources, such as hand-held devices [7], [8] or the electric field measured at a place for far-field sources [9] is evaluated. Additionally, current metrics do not take user QoS into account, including various ways in which EMF levels could be reduced while maintaining the required QoS. Moreover, this large number of existing metrics can be overwhelming: achieving a wide consensus on a smaller set of simple, relevant, accurate, yet all-encompassing metrics will permit to reliably compare different methodologies / systems and accelerate the research and standardization activities towards low-EMF wireless communications. What is lacking are methods to assess the exposure incurred amongst a given populace due to multiple sources, which is required to enable system adaptation towards low-EMF, QoS-aware configurations.

### Population exposure

The results of the survey presented earlier in this paper illustrate the biased view of the public on RF exposure, overestimating exposure from far-field sources (i.e. base stations and access points) and underestimating exposure from near-field sources (e.g. mobile terminals). However, measurements on real networks have shown a strong correlation (Figure 3) between the power emitted by personal devices and the power received by personal devices from the base station antennas [10].

As highlighted above, the question of RF-EMF exposure has so far been focused on the individual user, handling the exposure induced by personal devices and that of the network equipment separately. LEXNET will change this by putting the issue of the exposure not at the individual level but at the network level and by introducing exposure into network optimization. To this end, we propose a new exposure metric



**Figure 3** Duality between mobile phone emitted and received powers measured on the 3G Orange France network.

which we term the Exposure Index. The Exposure Index is associated with a given wireless telecommunication network, without taking into account the background exposure induced by other RF sources such as FM radio or DTT transmitters. This Exposure Index merges the exposure incurred by personal devices with that attributable to base stations and access points, thus becoming a new parameter to be reduced as part of network optimization: this includes developing novel radio-link technologies and network topologies which minimize this Index, together with network management techniques for these new as well as existing components that incorporate the Index in their optimization.

In a nutshell, the LEXNET Exposure Index is a function transforming a highly complex set of data into a single parameter which has two key benefits: it is understandable and



**Figure 4** The tree of representative exposure scenarios.

The building block in the exposure assessment remains the SAR. The SAR will depend on the morphology and the posture of the user and on the far-field and near-field sources. As part of LEXNET, a set of numerical dosimetric simulations will be performed in order to fill out a comprehensive matrix of raw maximal SAR values. In real conditions of use, SAR values are not maximal and network simulation tools and measurements of KPIs by sensors inside the network will then provide the levels to apply to the raw SAR matrix. Finally, the Exposure Index shall be calculated by crossing the database of SAR values with the set of configurations of exposure:

acceptable for all the stakeholders, from general public to regulatory bodies; and it is linked in a tangible way to the network operating parameters. The Index will take into account various data including information on:

- the environment, by dealing with different geographies (as urban, suburban or rural) and different scenarios such as indoor or outdoor;
- the population living, working and travelling in the area of interest and the existing and emerging RATs (GSM / UMTS / LTE / WiFi etc.) and the different layers (with macro, micro, pico and femto cells) that users connect to;
- the device usage (making a phone call in a sitting posture will not lead to the same exposure as downloading data in a standing position);
- the time as the configuration of the network and type of usage depend on the time of day (low-load night-time vs. heavily loaded peak-hour).

In summary, the Exposure Index shall cover the day-to-day exposure of people in a given area incurred by the entire wireless network from base stations to individual devices. The Exposure Index shall aggregate the downlink exposure induced by the base stations, the uplink exposure induced by the devices in communication, the different usage patterns, the category of users (children or adults), the user posture and device position with respect to the body of user, the different environments such as indoor or outdoor, the different RATs and layers in the network, and the different periods of the day. A set of technical data are going to be considered and aggregated in a Tree of Exposure (Figure 4). Each branch of the Tree is a possible scenario. Different exposure scenarios are considered and aggregated by putting weights on each configuration, thereby determining the Index, as will be further explained below.

$$EI = \sum_i \sum_j \sum_k \sum_l \sum_m f(SAR^{UL}, \bar{P}_{TX}, t^{UL}, SAR^{DL}, \bar{S}_{RX}, t^{DL})$$

with the summation over

- $i$  depicting the summation over different times of day
- $j$  depicting the summation over all the population in the area
- $k$  depicting the summation over all considered environments (indoor, outdoor etc.)
- $l$  depicting the summation over all the RATs and layers in the area
- $m$  depicting the summation over all the usage types

The exposure index is a function of different parameters obtained from numerical dosimetry, from network simulations or measurements and from usages. The  $\bar{P}_{TX}$  power is the mean emitted power by the users' devices during the period  $i$ , for the segment of population  $j$ , in usage mode  $m$ , connected to RAT  $l$ , in environment  $k$ .  $\bar{S}_{RX}$  is the mean received density of power during period  $i$ , for the segment of population  $j$ , connected to RAT  $l$ , in environment  $k$ . The values  $SAR^{UL}$  and  $SAR^{DL}$  are extracted from the raw matrix and the power  $\bar{P}_{TX}$  and the density of power  $\bar{S}_{RX}$  are the levels to be applied in order to obtain actual exposure. Duration of each configuration is given by  $t^{UL}$  and  $t^{DL}$ .

LEXNET will take advantage of the Index by adding it as a new wireless networks KPI. The aim is to minimize the Index of a population induced by a network in a given area. It is worth pointing out that this optimisation may lead locally (from a spatial and / or temporal perspective) to a higher exposure as assessed by existing metrics (which treat DL and UL separately) but to a lower value of the Index. As an illustration, let us consider the exposure of a population to a full macro 3G network versus the exposure of the same population with a heterogeneous 3G network composed of macro cells and femto cells. By adding the femto cells, the downlink exposure may in some cases increase as the exposure from the femto cell is added to the one of the macro. But the uplink exposure will be strongly decreased if the devices are connected to the femto cell rather than to the macro cell and the Index will be lower than in the case of a full macro cell network.

On this basis, LEXNET aims at investigating technical solutions to reduce the Index in different reference scenarios.

## Radio link components and EMF

The future networks envisaged by LEXNET will need to integrate flexible hardware at both the access nodes and user terminals, which enables limiting superfluous emissions by adapting transmission parameters to the specific environment and network characteristics.

Antenna design can play a key role in exposure reduction. Architectural constraints and solutions are very different for mobile handsets and access nodes (base stations / access points). For mobile phones, EM shield solutions have been considered to decrease EMF levels; however, antenna miniaturisation and high integration level can decrease the benefits of the shield, due to diffraction and current flowing on the edge of the handset board. The use of absorbers (such as ferrite layers) can solve the above issue, but it also impacts the antenna efficiency. LEXNET project will study meta-material design between the antenna and the body and its use as a reflector or as a filter of surface waves on the handset board. This requires additional complexity with respect to classic solutions; however, it does not affect the antenna efficiency over a large frequency bandwidth. At conventional macro cell base stations, radiation pattern agility has been extensively studied to improve the budget link. By focusing the radiated

energy only where it is useful, global exposure can be decreased. However, the current architectures are not compatible with low power node dimensions. LEXNET will therefore investigate miniature and directive antennas solutions to be integrated on typical small cell equipment while balancing the bandwidth / dimension / directivity / efficiency tradeoffs.

Besides the antenna, other components are indirectly related to the radiated energy. In existing solutions, radio access devices radiate signals even in idle mode to transmit signals required to offer continuous and ubiquitous coverage. Therefore, by introducing efficient sleep and wakeup mechanisms, it is possible to avoid needless EMF exposure while maintaining the user QoS.

One challenge is to design a self-organizing architecture and related optimization policies able to control the hardware components as well as to decide when and which access nodes have to be activated. Furthermore, this framework requires adaptive power amplifiers, which are able to limit the transition time between the two states. For instance, enabling fast deactivation/activation stages during time slots without/signal transmission can enhance the system efficiency.

The above discussed paradigm may reduce the radiated power due to downlink transmissions. On the contrary, designing more efficient low-noise amplifiers (LNAs) for the base stations may notably limit the radiation due to end-user terminals. Classic wideband LNA are configured for multi-band applications; however, this leads to poor noise figure. Furthermore, in current scenarios, transmissions are performed only on a single part of the available spectrum. Therefore, the usage of reconfigurable narrowband LNAs may improve the SINR at the receiver side, which in turn results in limiting the required power in the uplink.

## Radio link protocols and EMF

This section gives an overview of radio resource allocation techniques (with particular focus on power control and user scheduling) which have a significant impact on user EMF exposure. The way these resource allocation techniques impact EMF exposure, as well as additional parameters not commonly considered (such as device location with respect to the user and past exposure history), but which contribute to the overall exposure, are outlined. As will be shown here there exist radio link protocols that if properly configured could lead to significant EMF exposure reduction, and LEXNET will work on furthering such solutions.

As has been shown previously, by introducing efficient power control and handover management, wireless networks can efficiently reduce the user EMF exposure. LEXNET will increase the impact of power control by jointly optimizing it with radio resource management, allowing greater system improvements. As an example, delay-tolerant services can be accommodated when EMF exposure is lower.

Another important observation is the fact that reducing transmit power does not always equate to a commensurate EMF exposure reduction. In existing and emerging systems, common KPIs included transmit power, receiver SINR, interference levels, and so on. The EMF exposure however depends on several additional factors, including: types of devices; devices location with respect to the users; location of the users and their environment; specific frequency; morphology and age of the users; past exposure history; efficiency of discontinuous transmission schemes.

Taking these and other additional factors into account will enable LEXNET to assess the EMF exposure and thus reduce the transmit power only when critical from the EMF exposure point of view, thereby conserving the QoS in scenarios where conventional techniques would “blindly” (and therefore perhaps unnecessarily, at least from the user EMF exposure point of view) reduce transmit power. It should also be noted that many of the transmit power control parameters and tools are network-specific and that their impact is heavily dependent on the actual traffic load. On that note, as the traffic of 3G/4G systems increases, the commonly held views of their superiority over GSM in terms of user exposure may need to be revisited. An additional complication for power control in emerging networks is the cross-tier interference in HetNets, which is a potentially significant impediment in the successful deployment of small-cell systems and can impact the EMF levels considerably.

Allocating frequency-time-space radio resources for a single user is another radio management technique with (as will be shown here) potentially significant impact on EMF. Fast Link Adaptation (LA) and MIMO communications require dynamic knowledge of the channel characteristics, which is acquired by periodically transmitting pilots known to the receiver. Furthermore, to achieve ubiquitous coverage and maintain backward compatibility, system information and control symbols are continuously transmitted across the entire bandwidth, resulting in considerable overhead. We highlight here key adaptive mechanisms that have the potential to mitigate the EMF exposure by limiting the system overhead.

For services such as VoIP, timing and amount of radio resources are known in advance, and persistent scheduler can be implemented at the eNB to allocate predefined resources in a regular pattern, thereby significantly reducing control signalling overhead (and potentially EMF exposure).

To limit signalling and complexity, slow LA can be used to adapt transmission parameters only to slow channel variations (i.e. neglecting fast fading). This approach is characterized by reduced spectrum efficiency with respect to fast adaptation schemes; however, it may introduce notable gain in terms of EMF. Additionally, some antennas may be muted in the process called “MIMO muting” depending on traffic and QoS requirements.

Impact of the specific scheduling algorithm is also potentially significant. For dynamic scheduling it has been

shown that potentially significant savings in the number of signalling bits required for the mobile terminals to indicate the status of their data buffers to the scheduling node are possible depending on the specific scheduling algorithm applied [11]. Additionally, there have been studies which show that LTE and UMTS systems could benefit from the reduction in the resource allocation update rate at a diminished or no loss of performance depending on the selection of user scheduling algorithms [12]. This is potentially very valuable as EMF-aware scheduling algorithms may require signalling support of their own.

Finally, the joint implementation of the New Carrier Type (NCT) and cell discontinuous transmissions (DTX) may cope with inefficient operations at small cells. Discontinuous transmission is another way of reducing EMF. An entire cell can be “put into sleep mode”; this is known as Cell DTX. By using NCT, small cells will send only user-specific reference signals required for data transmissions, while classic control channel would be broadcast by overlaying macro eNBs. Furthermore, with cell DTX, idle small cells can be completely deactivated without affecting the network coverage. Algorithms for switching cells on and off depending on the traffic load are discussed in [13], with the main motivation being to conserve power. Similar ideas could be applied when the trigger is EMF exposure.

## Network management and EMF

This section gives a succinct overview of network management techniques which may lead to significant EMF levels reduction. As already pointed out, current network management techniques do not take into account EMF exposure, neither via EMF KPIs nor via EMF “alarms”. Nevertheless, various network management schemes use different EMF exposure “proxies”, which will be extended by LEXNET towards true EMF-aware techniques.

In wireless systems, network topology and the specific access technology as well as the duty cycle of the APs, have a significant impact on EMF exposure. In cellular networks, operators usually consider these factors when defining exclusion zones (areas in which the EMF exposure may exceed regulatory limits set for general public) surrounding the BSs. On the other hand, indoor network planning rarely analyzes RF-EMF exposure.

Network densification is seen as the chief approach to meeting the ever-increasing data rate requirements. Operators keep increasing the number of antennas per site to exploit spatial diversity techniques and also deploy additional low-power nodes to reduce the distance between end users and access points. These approaches can be beneficial from the EMF perspective, due to the reduction of the required uplink power. Nevertheless, such gain needs to be assessed against the aggregate radiation generated by multiple cells operating with different access technologies. Furthermore, as already discussed in previous section, base stations continuously transmit even when there is no data to send.

By adaptively managing the activity of neighbouring cells as well as the number of active antennas per cell site, this problem can be alleviated. In lightly loaded scenarios, adaptive mechanisms such as load balancing and cell zooming can be used to reduce the set of simultaneously active base stations and create temporarily optimal cells in terms of EMF, while satisfying QoS constraints. However, cooperative schemes like Coordinated MultiPoint (CoMP) transmission and reception have to be implemented to avoid coverage holes in the areas where inefficient base stations are deactivated. Inter-cell coordination has been traditionally introduced for mitigating or even harnessing the effect of interference especially at the cell edge; nevertheless, sharing CSI knowledge concerning users in cooperative cells makes it possible to perform optimal power allocation and beamforming, thereby reducing the EMF exposure due to data transmissions.

“Vertical handover” exploits the multi-RAT environment to locally select the best access technology for a given UE. At present, typical optimization parameters are the user spectral efficiency, load balancing, and energy saving. However, one of the objective of LEXNET is to evaluate which technology is the most EMF-friendly in a given scenario; hence, LEXNET will work on future vertical handover schemes which provide low-EMF communications over multi-RAT deployments.

In most of the existing work on access network selection the goal of reducing the EMF exposure has received little attention but there are various elements which can help to achieve this objective. 3GPP introduced a range expansion mechanism to expand the actual coverage area of small cells without increasing the downlink radiated power. However, this scheme mainly focuses on increasing the macro-cell offloading; it considers neither the cell backhaul capacity nor the EMF radiation related to the cell selection. 3GPP has also proposed the use of a standard Managed Object for the different information elements that could be used by the UE to discover and select an access network. So far, EMF is not taken into account within such process. Since an enhanced access network discovery and selection function should retrieve the user context from different databases, it is sensible to assume that “EMF user profiles” could be included within these repositories.

There is additionally room for disruptive techniques, which have not yet been considered in current technologies, but that can have result in notable improvement towards future EMF-aware systems. For instance, the relevance of so-called multi-hop topologies and relaying techniques is expected to increase in the short-term, even in cellular networks. In this context, a purpose-built management of the subagent topology and the routing methods will be crucial to lower the EMF while satisfying the QoS constraints. Additionally, device-to-device communication is an emerging framework for enabling to end-users which are in proximity to discover each other and to share data content without using the classic access network architecture (through access points, backhaul, etc). Hence, the

short-range nature of this enabling technology will allow to further limit EMF levels due to both downlink and uplink communications. Figure 5 depicts the key low-EMF networking enablers identified in this and previous sections.

## Conclusions and way forward

This paper has presented an overview of how the deployment of existing and emerging wireless networks impacts the resulting EMF levels. Attention has been drawn to the fact that the main focus of the existing EMF exposure evaluation framework is conformance testing using worst-case scenarios, in which wireless networks equipment and mobile terminals transmit at maximum power levels. The mounting worries about the exposure of end-users to EMF could change the users’ view of QoS, making EMF exposure an integral part of day-to-day network performance. What is more, mechanics of this “high QoS vs. low EMF” trade-off are different for different applications, services and usage scenarios. From the provided state-of-the-art overview, a clear need has surfaced for low-EMF, QoS-aware networking, which LEXNET will tackle.

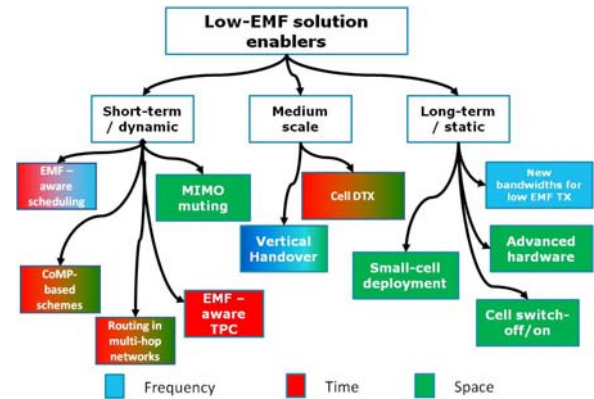


Figure 5 Overview of identified key low-EMF solution enablers.

In particular, LEXNET will focus on developing novel radio-link technologies and incorporating them into deployment of adaptive, self-organising network topologies and intelligent positioning of access points, with a view to reducing the EMF exposure while maintaining the QoS. Novel techniques are needed for management of new and existing network topologies whereby the EMF exposure is optimised jointly with the QoS. As has been demonstrated, existing network engineering services are very limited in this respect and the main challenge is therefore to include EMF into the optimization process by designing and implementing a population-based exposure metric that we term the Exposure Index and that takes into account exposure due to both personal devices and network transmitters.

It is important to stress that LEXNET is not redefining safety limits or re-evaluating effects of RF-EMF on human health. All the techniques LEXNET is developing are indeed compliant with existing safety regulations. The uniqueness of the LEXNET approach is that it builds upon existing metrics

by introducing the novel Exposure Index to quantify population exposure. This will enable the development of network management technologies which reduce EMF exposure without compromising the user QoS.

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