Scheme		CB					MRT				
	K \ N	4	16	36	64	100	4	16	36	64	100
T=60 s	1	0.70	0.40	0.31	0.23	0.22	0.73	0.43	0.32	0.25	0.22
	2	0.82	0.40	0.27	0.23	0.19	0.66	0.39	0.28	0.23	0.18
	5	0.92	0.43	0.29	0.23	0.19	0.64	0.36	0.27	0.20	0.16
	10	0.96	0.43	0.31	0.24	0.22	0.64	0.37	0.26	0.20	0.16
T=10 s	1	0.65	0.33	0.23	0.17	0.14	0.66	0.36	0.26	0.20	0.16
	2	0.80	0.34	0.22	0.17	0.14	0.62	0.34	0.24	0.19	0.15
	5	0.90	0.39	0.26	0.18	0.15	0.61	0.33	0.24	0.18	0.14
	10	0.95	0.42	0.29	0.22	0.17	0.61	0.32	0.24	0.18	0.14
T=1 s	1	0.64	0.30	0.20	0.15	0.12	0.67	0.34	0.25	0.19	0.15
	2	0.79	0.32	0.21	0.15	0.12	0.61	0.32	0.24	0.18	0.15
	5	0.90	0.37	0.25	0.17	0.14	0.60	0.31	0.23	0.18	0.14
	10	0.95	0.40	0.29	0.21	0.17	0.60	0.31	0.23	0.17	0.14

Figure 3. 95th percentiles of the 30-minute time-average BS gain fraction of the theoretical maximum.

S01-6 [11:45]
STUDENT PAPER

Protocol for 5G Personal RF-EMF Exposure assessment

Maarten Velghe[1], Sam Aerts[1], Luc Martens[1], Wout Joseph[1] & Arno Thielens[1]

[1]*Department of Information Technology, Ghent University/IMEC, Ghent, Belgium, 9052*
Keywords: Dosimetry (measurements), RF/Microwaves, Completed (published)
Presented by: Maarten Velghe

A new activity-based protocol for 5G microenvironmental measurements and survey studies for the assessment of personal RF-EMF assessment is proposed. This protocol provides a necessary update to reliably assess exposure in 5G technologies, as it addresses the main challenges to personal exposure measurements introduced by 5G NR. A systematic method to evaluate a user's auto-induced exposure is introduced by using an activity-based approach.

Introduction

Various methods have been developed to assess exposure to radiofrequency electromagnetic fields (RF-EMFs). Röösli et al. [1] proposed a protocol for such studies. In this protocol two basic types of RF-EMF exposure dosimetry studies are identified: population surveys (using measurements) and microenvironmental measurements. In a population survey, participants selected from the general public are given a personal exposure meter (PEM) and by keeping a diary of their activities, summary statistics on population exposure are obtained. In microenvironmental studies, a trained researcher performs the measurements in a way that represents the typical behaviour in the environment of interest. However, the 5th generation of telecommunications technologies (5G) will change the RF-EMFs to which the public is exposed [2], mainly because 5G NR (new radio) base stations use Massive Multiple-Input Multiple-Output (MaMIMO) to focus on user devices [3]. Hence, a person's downlink (DL) exposure will depend on whether they act as user. Thus, auto-induced exposure will no longer be limited to the UL exposure. Moreover, it is expected that the auto-induced fraction of the DL exposure will be the dominant component [4].

The objective of this paper is to present a general study protocol for future personal RF-EMF exposure research adapted to 5G technologies and accounting for auto induced exposure.

Throughout this paper, different sources of RF-EMF exposure are divided into five categories (Table 1).

A non-user is exposed to the categories in the second column and a user is exposed to all five categories. A user's exposure from data transmission DL depends on the position of the UE relative to the base station. In line-of-sight, the base station configuration leads to narrow beams towards the UE, while in non-line-of-sight, it leads to an EMF hotspot at the UE [5]. This is in contrast to legacy technologies, where data transmission DL occurs over a fixed beam covering a whole sector.

Focusing on users allows the network to use higher frequencies (3.5 GHz, 26 GHz, and 60 GHz are candidates).

Implications of 5G on personal exposure assessment

- The importance of auto-induced exposure will increase due to the introduction a-DL. Many studies currently omit this component
- a-DL exposure measurements are more susceptible to uncertainty than e-DL exposure measurements. Due to the narrow beams and hotspots aimed at the UE, there is a high dependence on the location of the measurement equipment relative to the UE.
- e-DL in 5G will be more spatially and temporally varied, increasing measurement uncertainty.
- Body-shielding of the measurement device by the user's body induces measurement uncertainty
- Larger bandwidths will be accompanied by more noise.
- UL, DL, and BC can all occur in the same frequency band. Therefore, using the current PEMs, it would be impossible to know what the source of the exposure is.

Proposed protocol

Activity-based exposure assessment

Two variables are important : (1) the location of the UE relative to the user and (2) the amount of data transmission in both UL and DL. The first is important because the user's exposure depends on the coupling of EM energy to the body, and it will affect the size and shape of the beam or hotspot aimed at the UE. The DL and UL transmissions are important because a higher EM power aimed at or emitted by the UE, implies a higher exposure of the user. Furthermore, a user's environmental exposure depends on the time and location within a microenvironment and the type of microenvironment.

Therefore, we propose to move towards an activity-based exposure assessment. An activity j (1…J) has eight attributes: the microenvironment m (1…M), the timeslot t (1…T), the position of the device p (1…P), and the measured power densities from five source categories: $S_{a\text{-}UL}$, $S_{a\text{-}DL}$, $S_{e\text{-}DL}$, S_{BC}, and $S_{e\text{-}UL}$. The position p is the area where the UE is during activity j.

Fig. 1 summarizes the proposed protocol. Here, exposure can be obtained directly from activities. The selected participants (on the left side of Fig. 1) are given a mobile device, which tracks their GPS coordinates, timing of telecommunication-related activities, the movement and proximity of the device relative to the body, and the amount of power emitted (resulting in $S_{a\text{-}UL}$) by the device. The device is also equipped with an (external) RF-EMF sensor measuring $S_{a\text{-}DL}$, $S_{e\text{-}DL}$, S_{BC}, and $S_{e\text{-}UL}$. Lastly the participants can optionally use a diary. The results are then used as input to a clustering analysis [6] in order to define J activities. For each activity j we then define an activity specific power density vector a_j:

$$a_j = [S_{aUL,j}\ S_{aDTDL,j}\ S_{eDTDL,j}\ S_{BCDL,j}\ S_{eUL,j}] \qquad (Eq.1)$$

with $S_{source,j}$ the measured power density from the specific source category during activity j. Next, the exposure received by the user is dependent on the position p of the device relative to their body. Therefore, we introduce a position coefficient $\beta_{source,j}$ transforming $S_{source,j}$ to the received power density on the body [7] based on simulations. This leads to a five-dimensional position coefficient vector β_j where the coefficients should be ordered in the same manner as for based on which source they apply to. Lastly, each activity has a duration fraction τ_j. The total exposure based on activities is shown at the bottom left of Fig. 1.

Microenvironmental measurements

To include auto-induced exposure in microenvironmental studies, a UE will be needed. The UE can download and upload data during the measurement in a controlled manner, emulating a specific user activity. During the measurement the researcher should keep the UE at a fixed position, from where the measured power density values can be transformed to received power density values.

On the right side of Fig. 1 the flowchart of the proposed procedure for microenvironmental studies is shown. In each microenvironment m (1…M), timeslot t (1…T), and scenario k (1…K) we define a scenario-specific power density vector S_{kmt}:

$$S_{kmt} = [S_{aUL,kmt} \;\; S_{aDTDL,kmt} \;\; S_{eDTDL,kmt} \;\; S_{BCDL,kmt} \;\; S_{eUL,kmt}] \qquad (Eq.2)$$

with $S_{source,kmt}$ the measured power density from the specific source category during scenario k, in microenvironment m and during timeslot t. These scenario-specific power density vectors can be combined to estimate the total exposure per microenvironment and timeslot, see Fig. 1.

Measurement Equipment

As shown in Fig. 1, a combination of two devices is proposed: (1) a personal exposure meter (PEM) and (2) a mobile device connected to the 5G NR network. The novel PEM will be used to measure both environmental and auto-induced 5G NR exposure.

To experimentally assess the exposure of a user in a 5G NR network, UE is needed to attract (a) beam(s)/hotspot(s) in both survey studies (as the participant's user device) and microenvironmental measurements. Besides the possibility of inducing a-DL and a-UL exposure, which can then be measured with the PEM, the device can be equipped with an application to log the Received Signal Strength Indicator (RSSI) from which S_{BC} could be derived (after calibration). Equipping the mobile device with an RF-EMF sensor such as DEVIN would further enable one to keep track of a-UL exposure.

In order to calculate β_j per activity j from survey studies, the location of the mobile device (the UE) relative to the body during the activity should be known. The location p of the UE is representative for the area where the UE can be during activity j (e.g. against the ear, in a handbag…). The area where the mobile device is can be derived by using existing smartphone proximity sensors, gyroscopes, alternative methods of monitoring and statistics on biomechanical movements..

Measurement procedure

For a microenvironmental study, first, the microenvironments and timeslots to be assessed are identified. Then, the scenarios which the mobile device should cycle through are selected. Since more scenarios means less time that can be spent in each scenario, we propose a total of four scenarios (each time simultaneous): maximal UL and DL data throughput, minimal UL and maximal DL, minimal UL and DL, and airplane mode. In each microenvironment a measurement path is defined [8].

Discussion

In Eq. 1 we defined total exposure in terms of power density$a_j$during each activity j. With the evolution of user data collection, it will be possible to calculate the τ_j's, the fraction of time spent in each activity, for many users. The distribution of RF-EMF exposure in the population can then be assessed on an individual level, with survey studies providing β_j and a_j. This will be extremely useful for epidemiological studies.

Challenges of future work include: (1) the design of measurement equipment according to the requirements described in this paper, (2) numerical simulations validated by lab measurements in order to calculate the position coefficient vectors β_j, (3) trial runs of the proposed survey study protocol and microenvironmental measurements protocol.

Conclusions

In this paper, the implications of the roll-out of 5G NR (new radio) on personal exposure to RF-EMFs are identified. These present challenges for personal exposure measurements. A new protocol based on the activities of users is proposed in order to overcome these challenges. This protocol includes the assessment of auto-induced exposure, which is an important part of personal exposure to RF EMFs that is currently not measured in most studies. .

References

[1] Röösli, et al. 2010. Env. Health 9(1).

[2] Aerts, et al. 2019. IEEE Access 7:18468-67.

[3] Marzetta, 2010, IEEE TWC 9(11):3590.

[4] Baracca, et al. 2018. Arxiv: 1801. 08351.

[5] Shikhantsov, S. et al. 2019. IEEE Access 7:21020-31.

[6] Tognola, et al. 2019. IJERPH 16(7):1230.

[7] Foerster, et al. 2018. Env. Health Persp. 126(7):077007.

[8] Thielens, et al. 2018. Env. Res. 162:81-96.

Figures

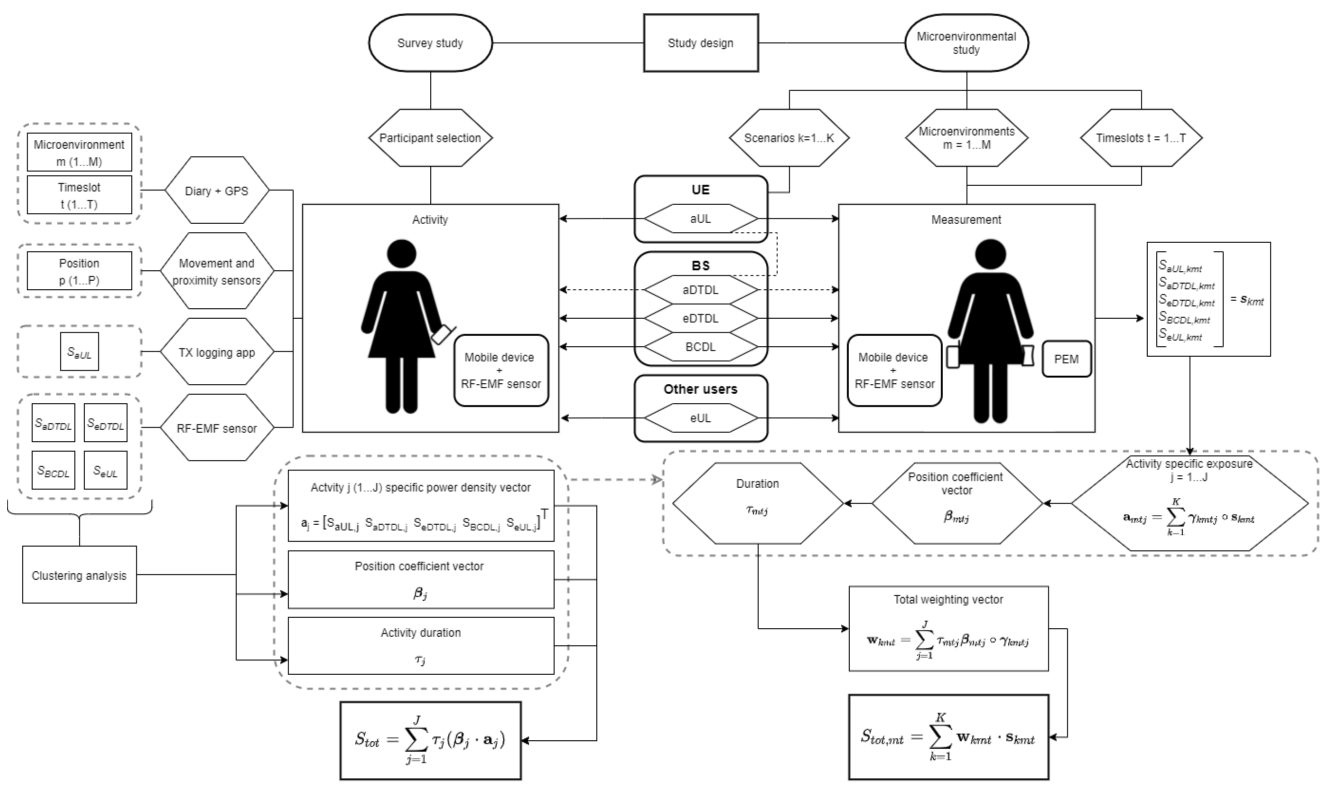

Figure 1. Flowchart of the measurement procedure for survey studies (left) and microenvironmental studies (right).

	Auto-induced (a-)	**Environmental (e-)**
Data transmission Uplink (UL)	Cat 1: Data transmission from a user's own device (user Equipment, UE) towards a base station.	Cat 3: Data transmission from devices of other, nearby users towards a base station.
Data transmission Downlink (DL)	Cat 2: In legacy technologies data transmission happens over fixed, cell-wide beams. In LTE-Advanced (4.9G) and 5G NR, narrow beams are aimed from base stations to the user device (in non-line-of-sight this results in a RF-EMF hotspot at the user device).	Cat 4: Narrow beams and hotspots aimed at and around other, nearby user devices.
Broadcasting (BC)	/	Cat 5: In many networks a control is sent out by the base stations to find potential users.

Figure 2. Table 1: Five categories of RF-EMF exposure sources: 2 auto-induced categories, 3 environmental categories.

BioEM 2021

26 - 30 Sep 2021, Flanders Expo, Ghent, Belgium

The Joint Annual Meeting of
The Bioelectromagnetics Society and the
European BioElectromagnetics Association

Abstract Collection