B46 and FB10

Assessment of 4G and 5G uplink exposure measured with three devices in different microenvironments in the city of Ghent

Mr Bram Stroobandt[1], Mr Han Van Bladel[1], Mr Samuel Goegebeur[1], Dr Sam Aerts[1,2], Mr Kenneth Deprez[1], Mr Maarten Velghe[1,3], Ms Leen Verloock[1], Miss Adriana Fernandes Veludo[4], Prof Martin Röösli[4], Prof Mònica Guxens[5], Prof Wout Joseph[1]

[1]Ghent University - imec, Ghent, Belgium. [2]The Hague University of Applied Sciences, Delft, Netherlands. [3]National Institute for Public Health and the Environment (RIVM), Bilthoven, Netherlands. [4]Swiss Tropical and Public Health Institute (Swiss TPH), Allschwil, Switzerland. [5]ISGlobal, Barcelona, Spain

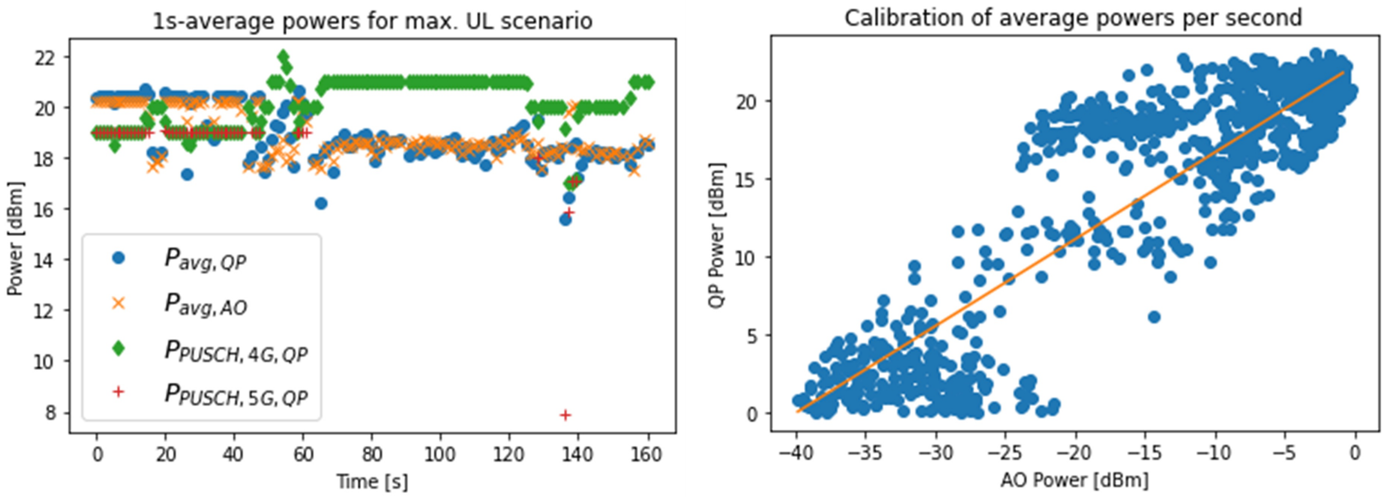
Abstract Subject Area(s)

["RF/Microwave"]

Upload file

Download file

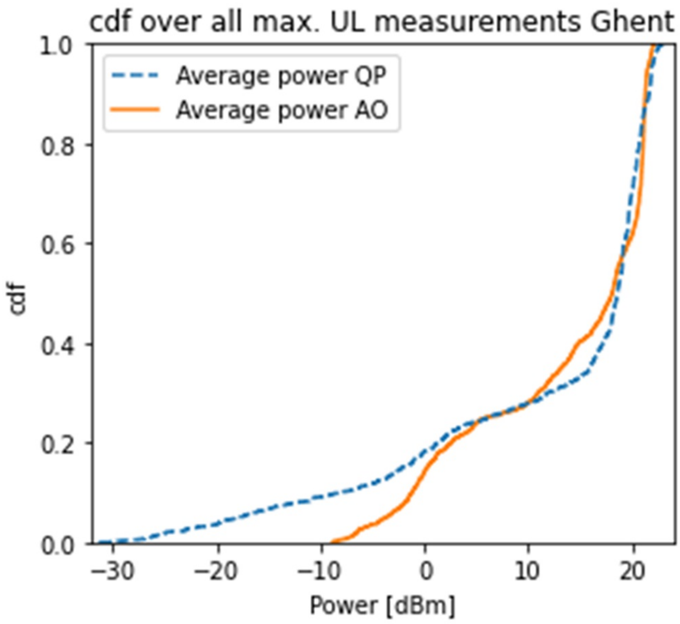
Upload figures



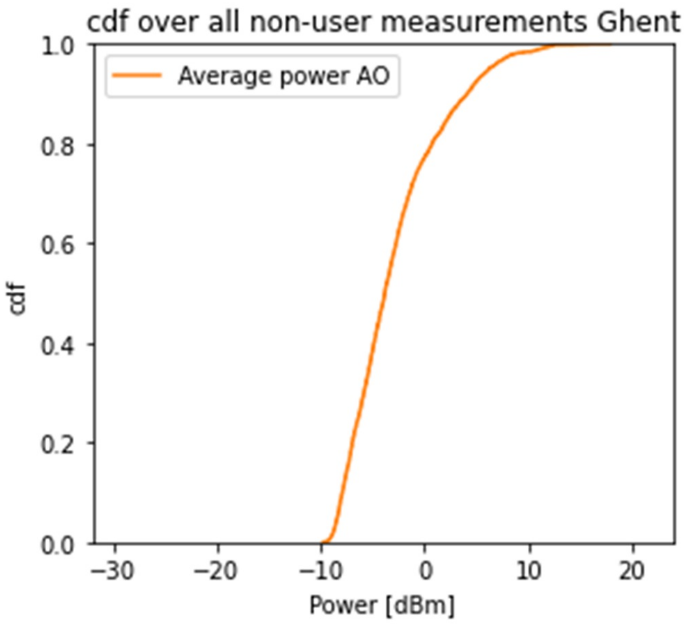
(a)

(b)

Upload figures 2

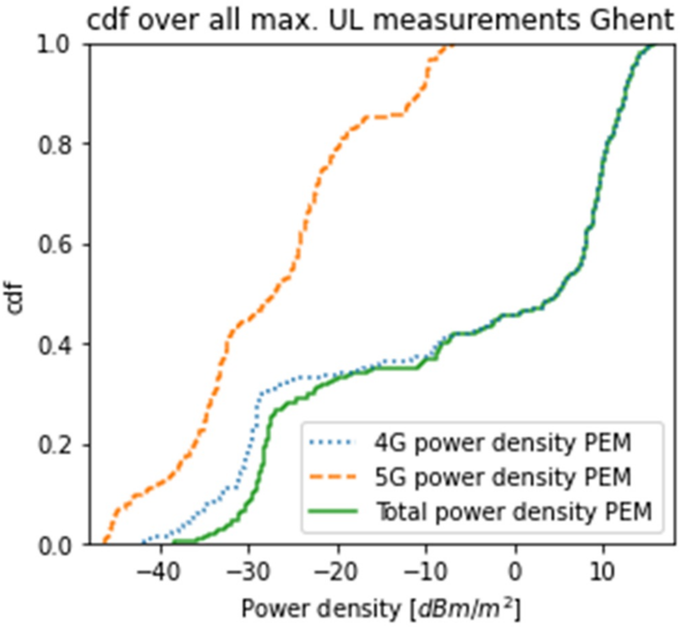


(a)

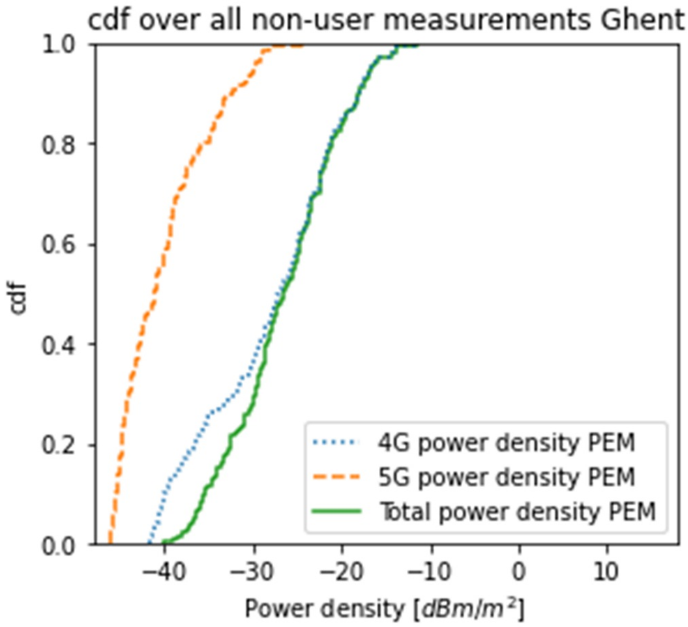


(b)

Upload figures 3



(a)



(b)

INTRODUCTION

With the deployment of 5G New Radio (NR), new challenges arise to measure radiofrequency electromagnetic field (RF-EMF) exposure. The use of beamforming to steer the base station signals towards connected users will result in high spatio-temporal variations of the RF-EMF. This leads to higher measurement uncertainties for personal exposure measurements. Additionally, in a 5G NR network, the RF-EMF exposure will depend much more on the amount of data usage for 5G NR, an additional component to take into account to assess personal exposure [1, 2]. This study focused on auto-induced UL exposure, caused by one's own mobile phone usage, which is part of the total personal exposure [2].

Personal exposure measurements are usually done using personal exposimeters (PEM) [1]. They are easy to carry around, but also have their limitations. Body-shielding, added noise due to larger channel bandwidths, lack of synchronization with the 5G NR time division duplexing (TDD) scheme, and the unknown sources of exposure all add up to the measurement uncertainty of the PEM [1]. To be able to more accurately assess the exposure, this uncertainty needs to be reduced, e.g., by using additional measurement data. Previously, uplink (UL) powers in 4G and 5G telecom networks were determined experimentally in [4, 5]. In this study, a protocol for microenvironmental exposure measurements was considered with three measurement devices gathering data simultaneously: (1) a mobile phone equipped with a commercial drive test application, (2) an RF-EMF sensor attached to the phone and (3) a PEM.

The goal of this study is to assess the uplink (UL) power of 4G and 5G telecom signals using three different devices during two usage scenarios (max. UL exposure and non-user) in an urban environment. This work can be used for evaluating a measurement protocol in a real environment (e.g. the protocol proposed in [6]). It is part of the GOLIAT (5G expOsure, causaL effects and rIsk perception through citizen engAgemenT) project in which total RF-EMF exposure is investigated using measurements with different devices in different countries and microenvironments.

METHODS

Measurement configuration

Measurements were performed in 13 microenvironments (MEs) in the city of Ghent, Belgium, in December 2022. In four MEs (two residential areas: central and outskirt; one non-central public park; and one industrial area), walking routes were defined, and nine MEs consisted of public transport routes (two train rides, three tram rides, and four bus rides). A trained researcher performed a predefined walk of approximately 15 minutes in each microenvironment or went on the public transport with a measurement backpack containing three measurement devices. In all microenvironments, both 4G and (non-standalone) 5G were present, except during one bus ride.

Two usage scenarios were considered: non-user and max. UL exposure. For the non-user scenario, the phone was put on airplane mode and thus only environmental exposure was measured. For the max. UL exposure scenario, the phone uploaded a file of 500 MB repeatedly to an FTP server set up by Ghent University. A third scenario, max. DL exposure (which is also part of the GOLIAT measurement protocol, [6]), was used only for the in-situ calibration (Fig. 1b) and consisted of the phone uploading a file of 1 GB repeatedly to the same FTP server.

Measurement devices

The measurement backpack contained 3 measurement devices: in the top pocket, a mobile phone (OnePlus 9 Pro) that was equipped with QualiPoc (QP) (i.e., a commercial drive test application by Rohde & Schwarz) and an add-on device (AO) attached to the phone (i.e., the RF-EMF sensor proposed in [7]); in the bottom of the backpack, approximately 30 cm away, a PEM (ExpoM-RF 3, made by Fields At Work) was placed.

From the mobile phone with QualiPoc, network parameters such as uplink throughput, number of resource blocks and power of the physical uplink shared channel (PUSCH Tx power) [dBm] were obtained. These were values reported by the chipset of the mobile phone. The AO measured over a large frequency band, from 1 MHz to 8 GHz, and reported the average, minimum, maximum, and median values of the power [dBm] received per second [7]. It was assumed that (during the max. UL scenario) it measured mainly UL signals due to the proximity to the mobile phone or user equipment (UE). Finally, the PEM measured 16 frequency bands, among which the 4G mobile telecommunication bands at 800 MHz (band 20) and 1.8 GHz (band 3), as well as band 42 (3.5 GHz) which covers part of the 5G NR n78 band. The latter is currently the main 5G band in use in Europe. Samples of the instantaneous electric field level [V/m] were collected by the device every 3 seconds. There was no communication or synchronization between the three measurement devices. The synchronization was performed in a post-processing step, which added uncertainty to the measurement. Synchronisation was obtained by manually writing down the exact timestamp (precise to the second) when the measurement devices started measuring.

Data processing

To compare the devices with each other, different post-processing steps were required per measurement device. The average power per second $P_{avg,QP}$ [W] was obtained from QP as follows,

$$P_{avg,QP} = DC_{4G} \cdot P_{PUSCH,4G,QP} + DC_{5G} \cdot P_{PUSCH,5G,QP} \tag{1}$$

with $P_{PUSCH,QP}$ the physical uplink shared channel transmit power (PUSCH Tx power) [W] averaged over one second and DC the duty cycle of the specified mobile technology. $P_{PUSCH,QP}$ originates from user data being send by the UE (i.e., in the PUSCH). Other uplink signals, e.g. for network control, were ignored. The duty cycle (DC) is defined as the percentage of active UL transport blocks in a transmission interval and was computed for 4G and 5G separately using equation (2), with $Thrpt_{PUSCH}$ the 1s-average PUSCH throughput [bit/s], TBS_{avg} the 1s-average transport block size [bit] and TTI the minimal transmission time interval equal to 1 ms for 4G and 62.5 µs for 5G.

$$DC = \frac{Thrpt_{PUSCH}}{TBS_{avg}} \; TTI \tag{2}$$

This post-processing step was needed since the reported PUSCH Tx power is the “current transmitting power on physical uplink shared channel (PUSCH)”, not a measurement with a specific sampling time. Therefore, the 1-s average $P_{PUSCH,xG,QP}$ is an extrapolation of the active resource blocks (i.e., the resource blocks used to transmit data) to all resource blocks within that second, which may constitute a significant overestimation. Therefore, these overestimated powers were rescaled to realistic averages by multiplication with the average percentage of active uplink transport blocks within that second, called the duty cycle. From the add-on device, the average power per second $P_{avg,AO}$ [mW] was obtained by taking the 1-s average over the same interval as $P_{avg,QP}$. Furthermore, the instantaneous electric field measured by the PEM (sampled every 3s) was converted to power density [mW/m^2] and denoted as S_{PEM}.

Finally, an in-situ calibration to minimize the difference between QP and AO power data was performed. The power distributions of both devices were assessed for the two scenarios and their 95th percentiles were discussed. The power densities of the PEM were assessed for 4G and 5G separately as well as their sum $S_{PEM,tot}$, referred to as the total power density.

RESULTS

Comparison between QP and AO for in-situ calibration

Fig. 1a shows $P_{PUSCH,4G,QP}$ and $P_{PUSCH,5G,QP}$ together with $P_{avg,QP}$ for the max. UL exposure scenario during the first 160 s of a 15-minute walking path in a central residential area of Ghent. Also, $P_{avg,AO}$

after applying a calibration factor specific to the situation is shown. The 1-s average total powers measured with QP and AO, $P_{avg,QP}$ (blue dots in Fig 1a) and $P_{avg,AO}$ (orange crosses in Fig 1a), agree well, with averages in the ME equal to 80.14 mW and 79.40 mW, respectively, and standard deviations of 20.10 mW and 16.79 mW. To show the need for taking into account the DC (post-processing steps of equation (1) and (2)), the reported 4G and 5G PUSCH Tx powers $P_{PUSCH,4G,QP}$ and $P_{PUSCH,5G,QP}$ are also shown in Fig. 1a (green diamonds and red crosses, respectively). The averages were 104.82 mW and 75.74 mW, respectively, and standard deviations of 21.79 mW and 12.94 mW. Since the add-on device is measuring very close to the mobile phone, it measures mainly the uplink signals coming from the mobile phone. Therefore, the uplink Tx powers reported by QualiPoc follow closely the average Rx powers measured by the add-on.

Figure 1: 1s-average 4G-5G PUSCH Tx powers reported by QualiPoc (QP) and measured by the add-on (AO). (a) as a function of time during the max. UL scenario along a walking path in a central residential area of Ghent after applying a specific calibration faxtor to the AO data and (b) per second for the max. UL and max. DL scenario in all microenvironments in Ghent after data cleaning together with the linear calibration function.

Fig. 1b shows the 1-second averages $P_{avg,QP}$ compared to $P_{avg,AO}$ used for the calibration of the AO measurements. The lower limits were set to 0 dBm for QP powers and -40 dBm for AO powers. Outliers, namely samples with a squared error between the average powers of both devices outside the 95th and the 5th percentile of this error, were removed to account for the uncertainties described below. A linear fit of these remaining data points generated the linear calibration function of equation (3).

$$P_{QP}[dBm] = 0.557\ P_{AO}[dBm] + 22.246 \quad (3)$$

The add-on can measure the uplink Tx power of the mobile phone with a root-mean-square error of 3.17 dB. In the ideal case, all add-on Rx powers are linearly proportional to the Tx powers of the mobile phone. In practice, there are several reasons why this would not be the case. The add-on may capture signals in the environment other than those of the transmitting mobile phone, near-field coupling between the antennas of the add-on and the mobile phone may change the actual radiated power, there may be an error on the synchronization between the two devices, etc. These factors have a lower impact for high uplink powers because then other signals are dominated by the signal of the mobile phone where the add-on is attached to. In the following, the calibration function of equation (3) is applied to the add-on data.

Power distributions of QP and AO over all microenvironments

Fig. 2a shows the 1s-average power distributions reported by QualiPoc (QP) and the add-on (AO) for the max. UL and non-user scenarios over all microenvironments measured in Ghent. The distributions of QP and AO coincide very well for the max. UL scenario, except for the low powers. This is in line with the calibration between those two devices. The 95th percentiles are equal to 21.89 dBm and 21.50 dBm for QP and AO powers respectively. Median values are 18.59 dBm and 18.10 dBm. For the non-user scenario, the 95th percentile is equal to 6.19 dBm for the 1s-average AO power and the median is -3.83 dBm. No QP data is available for Fig. 2b since the mobile phone is in airplane mode. The received AO powers are generally low because they are all originating from far-field sources. Power values of the max. UL scenario (Fig. 2a) are of course clearly higher than those of the non-user scenario (Fig. 2b). Duty cycles during 5G uplink transmission varied between 0.0% and 49.9% with an average of 21.0% and 4G uplink duty cycles varied between 0.5% and 99.6% with an average of 66.5%. This is in line with [4] where 5G uplink duty cycles between 20% and 25% were found and [5] that reports 4G uplink duty cycles up to 73.7%. It shows that 5G uses less resources than 4G, which was taken into account by the post-processing step of equation (1).

Figure 2: Distributions of the average power [dBm] of QualiPoc (QP) and the add-on (AO) over all measurements for (a) the max. uplink exposure scenario and (b) the non-user scenario (no QP data available).

Power density distributions of PEM over all microenvironments

Fig. 3 shows the cumulative distribution function (cdf) of 4G and 5G UL power densities measured by the PEM for all microenvironments measured in Ghent. For the max. UL scenario, the 95th percentiles are equal to 21.93 mW/m^2, 1.08 10^{-1} mW/m^2, and 22.06 mW/m^2 for the 4G, 5G and total PEM UL power density, respectively. Median values are 3.20 mW/m^2, 1.91 10^{-3} mW/m^2, and 3.21 mW/m^2. For the non-user scenario, the 95th percentiles are equal to 2.12 10^{-2} mW/m^2, 1.03 10^{-3} mW/m^2, and 2.15 10^{-2} mW/m^2 for the 4G, 5G and total PEM UL power density, respectively. Median values are 1.93 10^{-3} mW/m^2, 7.90 10^{-5} mW/m^2, and 2.19 10^{-3} mW/m^2. In general, 4G UL power densities are much higher than 5G UL power densities for both scenarios. This is due to the higher duty cycles as explained above and in line with [4, 5]. The shape of the distributions of Fig. 2 and Fig. 3 are similar. Differences can be attributed to the difference in sampling speed and the separation between the UE and the PEM.

Figure 3: Distributions of the 4G, 5G, and total uplink power density [dBm/m2] of the PEM over all measurements for the max. Uplink (UL) exposure (a) and non-user (b) scenarios.

CONCLUSIONS

In this study, the RF-EMF exposure from 4G and 5G UL signals was measured with different devices: a mobile phone equipped with the drive test application QualiPoc and an add-on device attached to the phone. Also, simultaneously, power densities were measured with a PEM. Two usage scenarios were considered: non-user and max. UL exposure. The add-on device was calibrated in-situ with QualiPoc and good agreement was obtained with a root-mean-square error of 3.17 dBm. Measurements in different microenvironments within the urban environment of the city of Ghent provide 95th percentiles of 21.89 dBm and 21.50 dBm for QP and AO UL powers respectively, during the max. UL scenario. Using the personal exposimeter, 95th percentiles of 21.93 mW/m^2, 1.08 10^{-1} mW/m^2, and 22.06 mW/m^2 were found for 4G, 5G and total power densities respectively. Future work will consist of performing measurements with the different devices in different countries and microenvironments to assess exposure over usage as part of the GOLIAT project.

Acknowledgement

This work is part of the European Union's Horizon Europe research and innovation programme under grant agreement No 101057262 (GOLIAT) funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

REFERENCES

[1] Maarten Velghe, Sam Aerts, Luc Martens, Wout Joseph, and Arno Thielens, "Protocol for personal RF-EMF exposure measurement studies in 5th generation telecommunication networks," Environmental Health, vol. 20, no. 1, pp. 1–10, 2021.

[2] Martin Röösli, Patrizia Frei, John Bolte, Georg Neubauer, Elisabeth Cardis, Maria Feychting, Peter Gajsek, Sabine Heinrich, Wout Joseph, Simon Mann, et al., "Conduct of a personal radiofrequency electromagnetic field measurement study: proposed study protocol," Environmental Health, vol. 9, no. 1, pp. 1–14, 2010.

[3] Ae-Kyoung Lee, Sang-Bong Jeon, and Hyung-Do Choi, "EMF levels in 5G new radio environment in seoul, korea," IEEE Access, vol. 9, pp. 19716–19722, 2021.

[4] Paramananda Joshi, Fatemeh Ghasemifard, Davide Colombi, and Christer Törnevik, "Actual output power levels of user equipment in 5G commercial networks and implications on realistic rf emf exposure assessment," IEEE Access, vol. 8, pp. 204068–204075, 2020.

[5] Paramananda Joshi, Davide Colombi, Björn Thors, Lars-Eric Larsson, and Christer Törnevik, "Output power levels of 4G user equipment and implications on realistic RF-EMF exposure assessments," IEEE Access, vol. 5, pp. 4545–4550, 2017.

[6] Adriana Fernandes Veludo, Kenneth Deprez, Bram Stroobandt, Han van Bladel, Sam Aerts, Leen Verloock, Samuel Goegebeur, Stefan Dongus, Nicolas Loizeau, Gabriella Tognola, Marta Parazzini, Joe Wiart, Wassim Ben Chikha, Patricia de Llobet, Mònica Guxens, Wout Joseph, and Martin

Röösli, “Activity-based micro-environmental surveys in ten European countries to monitor radiofrequency-electromagnetic fields (RF-EMF): A measurement protocol,” in *BioEM 2023, Joint Annual Meeting of the Bioelectromagnetics Society and the European Bioelectromagnetics Association,* Oxford, UK, 2023, *submitted*.
[7] Han Van Bladel, Kenneth Deprez, Bram Stroobandt , Samuel Goegebeur, Sam Aerts, Leen Verloock, Luc Martens, and Wout Joseph, “Design, calibration and validation of a low-cost broadband add-on RF-EMF exposure sensor for legacy and 5G NR technologies,” in *BioEM 2023, Joint Annual Meeting of the Bioelectromagnetics Society and the European Bioelectromagnetics Association,* Oxford, UK, 2023, *submitted*.

BioEM 2023

THE 2ND ANNUAL CONFERENCE OF BioEM

TECHNICAL PROGRAM AND GENERAL INFORMATION

18 - 23 June 2023
Mathematical Institute
Oxford, United Kingdom

BioEM