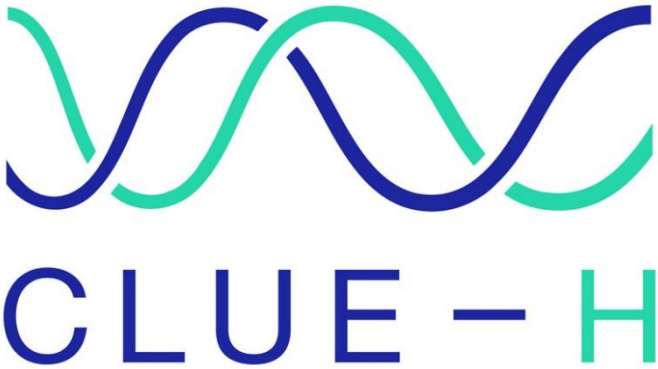

European Cluster EMF and Health

Deliverable
Scientific strategy of the cluster

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Executive Summary

This deliverable presents the scientific strategy of the European Research Cluster on Electromagnetic Fields and Health (CLUE-H) which includes the creation of two working groups that will enable project representatives to coordinate their efforts and align their work on topics of common interest, as well as the organization of four thematic workshops/trainings on topics of common interest.

1 Introduction

The overall aim of the deliverable “Scientific strategy of the cluster” is to identify key scientific topics that will potentiate synergies across the four CLUE-H projects (i.e., SEAWave, NextGEM, ETAIN, GOLIAT).

Based on the objectives and work carried out in this deliverable, the document starts with the Executive Summary followed by the introduction of the document in Section 1.

Section 2, describes the working groups that will enable project representatives to coordinate their efforts and align their work on research topics.

Section 3 presents the thematic workshops/trainings on topics of common interest.

Finally, Section 4 gives a short conclusion about this report.

2 Working groups

As part of developing synergies within CLUE-H, the scientific synergies are mostly related to the working groups (WG): WG4 Experimental studies and WG5 Exposure assessment. Below we describe these WG.

2.1 Working group 4: Experimental studies

The WG on experimental studies is responsible for establishing common strategies and joint activities at experimental level in the Cluster, and maximizing the impact of the CLUE-H results.

The objectives of this WG include:

- to identify activities and common approaches where synergy is possible;
- to exchange knowledge, protocols and best practices to improve the experimental design and render the results more effective for the purpose of health risk evaluation;
- to cluster and compare the results;
- to foster joint publications, where applicable.

In order to achieve these objectives, the WG will develop the following activities:

- to identify the key researchers from each CLUE-H project to be part of this WG
- to establish a discussion among these key researchers ;
- to map the experimental activities by single project;
- to identify the study types where synergies are possible, and establish related sub-groups;
- to foster small adjustment of the activities planned in the single projects, where applicable, to maximize the impact of the results;
- to identify common strategy for clustering and comparing the results.

So far, the undertaken work has been the following:

- Summary tables have been prepared to map the experiments (i.e., *in vitro*, *in vivo*, humans) in the 4 projects and shared within the WG, with the aim of identifying synergies;
- Synergies appeared feasible in the case of in vitro studies and in vivo studies on insects/worms where comparable conditions are planned in the 4 projects;
- Preliminary summary tables have been prepared for in vitro studies (Table 1) and in vivo studies on insects/worms (Table 2) by sorting the activities by biological endpoints;
- The specific experimental conditions are under examination, definition, and adjustment to establish synergies.

The WG is coordinated by Olga Zeni (NextGEM) and Mònica Guxens (GOLIAT). WG members from the other CLUE-H project are represented by Annette Bitsch, Christina Ziemann, Michelle Angelica Djuari (SEAWave), Isabelle Lagroye, Florence Poulletier-de Gannes, and Christelle Lasbleiz (ETAIN), and Isabelle Lagroye, Yann Percherancier, and Giorgio Aicardi (GOLIAT). The meetings will be held preferably online throughout the individual projects' duration, and in person when possible (e.g., at the BioEM conferences, the CLUE-H yearly meetings). WG members with specific synergies may meet at other times, online or in person, with a planning based on need.

Table 1: Mapping of CLUE-H *in vitro* studies

Oxidative stress						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Skin cells / fibroblasts / keratinocytes / reconstituted skin cell sheets	ROS production and induced gene expression / Mitochondrial function	3.5	100 MHz	0.08, 0.4, 4 W/kg	Up to 1h	GOLIAT
		26	100 MHz	0.3, 3, 30 W/m^2	Up to 1h	GOLIAT
Skin cells / keratinocytes	ROS production	3.5	100 MHz	10 mW/kg - 100 W/kg (exact SAR TBD)	1-24h	NextGEM
		26.5	100 MHz	0.3-1.25 W/kg	1-24h	NextGEM
Skin cells / fibroblasts	ROS production	3.5	100 MHz	0.08, 0.4, 4 W/kg	Real time	ETAIN
		26	100 MHz	0.3, 3, 30 W/m^2	Real time	ETAIN
3D commercial epiderm model	Antioxidant defense	3.5	100 MHz	0.08, 0.4, 4 W/kg	1-2h to 1-2 days	ETAIN
		26	100 MHz	0.3, 3, 30 W/m^2	1-2h to 1-2 days	ETAIN

Epigenetics						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Skin cells / keratinocytes	DNA methylation / Telomere length	3.5	100 MHz	10 mW/kg - 100 W/kg (exact SAR TBD)	1-24h, 3 weeks	NextGEM
Skin cells / keratinocytes	DNA methylation / Telomere length	27.5	100 MHz	0, 3.3, 10 W/m^2 (uncertainty TBD)	Up to 7 days, 10 min On / 10 min Off	SEAWave

Transcriptomics						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Skin cells / keratinocytes	Transcriptomics and gene expression of selected genes	3.5	100 MHz	10 mW/kg - 100 W/kg	1-24h, 3 weeks	NextGEM
		26.5	100 MHz	0.4, 1 W/kg	1-24h, 3 weeks	NextGEM
Skin cells / keratinocytes	Transcriptomics	27.5	100 MHz	0, 3.3, 10 W/m^2 (uncertainty TBD)	Up to 7 days 10 min On / 10 min Off	SEAWave
3D reconstructed model	Transcriptomics and metabolomics	26	100 MHz	Optimal S_{abs} (max 10 W/m^2)	Optimal exposure conditions	ETAIN

Mechanisms at molecular level						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Red blood cells	Responses of hemoglobin solutions / modifications of thiol and amino groups (glutathionylation, glycosylation) Changes in protein structure/ bound water	0.9, 2.5, 3.6, 26	100 MHz	TBD (under development, as of March 2024)	10min – 3h	NextGEM
In silico	Molecular modelling of SOD1 enzyme	3.5	100 MHz	0.08, 0.4, 4 W/kg	Hundreds of ns	GOLIAT
		26	100 MHz	0.3, 3, 30 W/m^2	Hundreds of ns	GOLIAT

Thermoregulation and thermosensitive ion channels						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Skin cells / fibroblasts	TRPV4 / TRPM8 / TRPM2 / TRPA1 functionality	0.7, 3.5	100 MHz	Up to 35 W/kg	Up to 1h	GOLIAT
		26	100 MHz	Up to 100 W/m^2	Up to 1h	GOLIAT
Sensory neurons	TRPM8 ion channel function	0.7, 3.5	100 MHz	0.08, 0.4, 4 W/kg	30s, 24h	GOLIAT
		26	100 MHz	0.3, 3, 30 W/m^2	30s, 24h	GOLIAT

Table 2: Mapping of CLUE-H in vivo studies on insects/worms

Fitness and development						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Drosophila melanogaster	Locomotor performances, development time	26	100 MHz	0.1, 1, 10 W/m^2	Up to 10 generations, during whole life cycle	ETAIN
Caenorhabditis elegans	Survival, reprotoxicity, development time	26.5	100 MHz	0.4, 1 W/kg	72h, during whole worm development	NextGEM
Calliphora vomitoria	Development time	1.8, 3.5, 26	0 MHz	0.6 mW/kg up to 13 W/kg	48h	ETAIN
Apis mellifera	Hive development, hive health	3.5, 26	100 MHz	0.1, 1, 10 W/m^2	3-4 months	ETAIN

Metabolomics and transcriptomics						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Drosophila melanogaster	Transcriptomics, metabolomics	26	100 MHz	Optimal S_{abs} (max 10 W/m^2)	At first and after 5 and 10 generations, during whole life cycle	ETAIN
Caenorhabditis elegans	Transcriptomics	26.5	100 MHz	0.4, 1 W/kg	72h, during whole worm development	NextGEM

Oxidative stress						
Model	**Endpoint**	**Frequency (GHz)**	**Bandwidth**	**SAR/S_{abs}**	**Exposure Time / On-Off cycles**	**Project**
Caenorhabditis elegans	ROS production	26.5	100 MHz	0.4, 1 W/kg	72h, during whole worm development	NextGEM

2.2 Working group 5: Exposure assessment

The WG on exposure assessment is responsible for aligning and/or comparing the RF-EMF measurement and exposure assessment procedures used in CLUE-H.

The objectives of this WG include:

- to share the WG members' insights and expertise on EMF exposure assessment in order to deliver clusterwide scientifically robust results;
- to exchange about current measurement methodologies for 5G NR Frequency Range 1 (FR1; 410 MHz and 7.125 GHz) exposure assessment and ensure their usability in maturing and continuously evolving 5G NR network topologies; and adapt them where necessary to Frequency Range 2 (FR2; 24.25 and 52.6 GHz);
- to exchange about current and/or develop novel measurement protocols for microenvironmental studies in 5G NR networks, taking into account the increased dependence of the exposure on the user behaviour ("auto-induced exposure");
- to share experience and insight regarding novel measurement devices (especially custom-made sensors) for both FR1 and FR2 frequencies that enable assessing temporal variability (fixed sensor networks) as well as personal exposure (on-body sensor networks) of users, the general public, and workers in specific 5G-related scenarios;
- to exchange about various exposure and dose concepts used for epidemiological research and public communication;
- to exchange about and/or develop measurement protocols for a user's uplink exposure assessment, through the use of mobile-phone applications and/or dedicated hardware;
- to collaborate in the characterization of the uplink and downlink contributions to the total exposure, in individuals and in the global population where possible;
- to exchange about models of the global exposure using statistical and AI approaches with environmental and global usage parameters as input;
- to share insights into transfer functions to transpose downlink and uplink exposures to whole-body or organ-specific exposures;

In order to achieve these objectives, the WG will develop the following activities:

- to share relevant publications among WG members;
- to identify the measurement aims, target population, methods and used devices;
- to identify and connect WG members with the respective expertise pertaining to the above-listed aims;
- to assess if joint measurement campaigns, such as at a 5G test site (e.g., in Delft, The Netherlands), are feasible to perform given the different aims and timelines of the projects;
- to organize a workshop (in person, online, or hybrid) with WG group members to align methodologies where this would be helpful across the individual projects, and to share insights regarding measurement campaigns and devices, methods and calibration efforts;
- to realize a live (high-level) inventory of the measurement devices and applications (type, aim, and use) and measurement/calibration/validation methods used in the different projects (preliminary list in Table 3 and Table 4);
- to share newly developed tools and applications with partners, where appropriate.

The WG is coordinated by Sam Aerts (NextGEM), Joe Wiart (SEAWave and GOLIAT), and Mònica Guxens (GOLIAT). WG members from ETAIN are represented by Martin Roosli, Hamed Jalilian, and Juerg Froehlich. The meetings will be held preferably online throughout the individual projects' duration, and in person when possible (e.g., at the BioEM conferences, the CLUE-H yearly meetings, the URSI conferences, the ISES-Europe conferences, COST INTERACT meeting/conference). WG

members with specific synergies (e.g., uplink measurements) may meet at other times, online or in person, with a planning based on need.

Table 3: High-level inventory of RF-EMF measurement devices / applications used in each project.

Measurement devices / applications	Project	Use
Custom-made FR1 sensor, for use in a fixed network	NextGEM, GOLIAT, SEAWave	Long-term monitoring (at fixed locations) of FR1 frequencies
Custom-made FR2 sensor, for use in a fixed network	GOLIAT, SEAWave	Long-term monitoring (at fixed locations) of FR2 frequencies
Custom-made FR1 sensor, for use in on-body network	NextGEM	Personal FR1 exposure measurements
Custom-made FR2 sensor, for use in on-body network	NextGEM	Personal FR2 exposure measurements
Custom-made broadband sensor (on skin)	ETAIN	Personal exposure measurements
Spectrum (& signal) analyzer	GOLIAT, SEAWave, NextGEM	- Spot measurements (GOLIAT, NextGEM) - Mobile measurements (SEAWave)
Commercial exposimeter	GOLIAT, SEAWave	- Microenvironmental measurements of general public and exposure measurements of workers (GOLIAT) - Measurements of general public exposure (SEAWave)
Car-mounted measurement system	SEAWave	Drive measurements, covering wide geographical area
Custom-made mobile phone output power sensor	GOLAT, SEAWave	Mobile phone output power measurements
Custom-made mobile phone application	ETAIN	Mobile phone network parameter measurements
Drive-test tool	GOLIAT, SEAWave	- Mobile phone network parameter measurements (SEAWave, GOLIAT) - Intercomparison of drive-test tools (SEAWave) - Calibration of custom-made mobile phone output power sensor (GOLIAT)

Table 4: High-level inventory of RF-EMF exposure assessment methods used in each project.

Exposure assessment method	Project	Use
Ray-tracing	NextGEM	Modeling of exposure in 5G networks
Artificial Intelligence	SEAWave	Use of Artificial Neural Networks (ANN) for global exposure modeling
Statistical modelling	SEAWave, ETAIN	- Global exposure from extensive set of measurements (SEAWave) - Personalized exposure from calibrated phone measurements (ETAIN)
Microenvironmental survey	GOLIAT	Measurement protocol with exposimeter and mobile phone in backpack, simulating (1) non-user, (2) max DL user, and (3) max UL user
Uplink measurements	GOLIAT, SEAWave, ETAIN	- Drive-test tool + custom-made sensor (GOLIAT) - Drive-test tool + custom-made sensor (SEAWave) - Custom-made phone app (ETAIN) - Measurements of UL from other users (SEAWave)
Downlink measurements	GOLIAT, SEAWave, NextGEM, ETAIN	- Spot measurements (GOLIAT, SEAWave, NextGEM) - Drive measurements (SEAWave) - Sensor measurements (GOLIAT, SEAWave, NextGEM) - Mobile (bike) measurements (ETAIN) - Citizen science measurements (App) (ETAIN)
Indoor measurements	GOLIAT, SEAWave	- Public transport (GOLIAT, SEAWave) - Public buildings (GOLIAT) - Schools (GOLIAT) - Workplaces (GOLIAT, SEAWave)
Outdoor measurements	GOLIAT, SEAWave, NextGEM, ETAIN	Public places, transport, different cities (GOLIAT, SEAWAVE)
EMF dose modeling	ETAIN, GOLIAT	Assess overall EMF energy absorption
Transfer functions to transpose measurements to organ-specific exposure	SEAWave, ETAIN	Assess organ-specific EMF energy absorption

3 Thematic workshops/trainings

As part of developing scientific synergies within CLUE-H, we will organize five thematic workshops/trainings on topics of common interest. The specific topics are still under discussion, but a preliminary proposal is the following:

- Course on "EMF and Health from an epidemiological perspective"
  - Organizers: Anke Huss (ETAIN) and Mònica Guxens (GOLIAT)
  - 6-12 April 2024 (corresponding to Month 18 of the cluster)
  - At the International School of Bioelectromagnetism “Alessandro Chiabrera”, Erice, Sicily
- Workshop on "Exposure assessment and dosimetry with numerical and experimental techniques"
  - Organizer: Theodoros Samaras (SEAWave)
  - June 2024 (corresponding to Month 24 of the cluster)
  - At the BioEM conference, Chania, Crete
- Workshop on "EMF and Health Cluster of European Projects (CLUE-H)"
  - Organizers: Nikolaos Petroulakis (NextGEM), Anke Huss (ETAIN), Mònica Guxens (GOLIAT), Theodoros Samaras (SEAWave)
  - June 2024 (corresponding to Month 24 of the cluster)
  - At the BioEM conference, Chania, Crete
- Workshop on "Societal and Ethical Impacts of RF-EMF research" (under development, as of March 2024)
  - Organizer: Deborah Oughton (GOLIAT)
  - Date TBD (around Month 36 of the cluster)
  - Location TBD
- Last workshop/training TBD (around Month 48 of the cluster) (under development, as of March 2024)

4 Conclusion

This deliverable provided the main scope of the scientific strategy within CLUE-H. That includes the structure, the objectives, and the type of experiments of Working Group 4 (Experimental Studies) and of Working Group 5 (Exposure assessment) as provided within this report. Moreover, the plans for thematic workshops and trainings are also described.