How beyond-5G frequencies will further enhance the next-generation wireless networks performance

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The BRAVE partners have launched in January 2018 an ambitious research project to explore how the sub-TeraHertz (sub-THz) spectrum above 90 GHz could make the future wireless communication technologies outperform 5G. The millimeter-wave bands between 10 and 90 GHz are extensively considered today for 5G deployments. Their connectivity range is much shorter than offered by the lower sub-6GHz frequencies exclusively used in previous mobile network generations. But the huge available bandwidth allows for ultra-high data rates (greater than 1 Gbps) especially in line-of-sight (when no obstacle) either for fixed wireless links or short-range device connectivity. The research in future technologies makes now conceivable the realization of communication systems that operate at sub-THz frequencies, from 90 GHz up to 0.3 THz: much larger bandwidths are available and thus new capacities can be exploited. Before such a promise becomes a reality, the feasibility and viability must be confirmed. Many challenges such as power feeding, energy efficiency, robustness to phase noise, wideband digitalization, antennas design, etc. are far from being solved, and have to be tackled by the scientific and engineering communities.

The White Paper summarizes the BRAVE vision on sub-THz applications and physical-layer technologies.

BRAVE is exploring new technologies that will answer emerging or future connectivity needs

The BRAVE project has two main objectives:

1) elaborate and evaluate innovative waveforms that are adapted to the particular properties of the sub-THz physical layer

2) identify which new applications could benefit from beyond-5G speeds, i.e. several hundreds of gigabit per second (Gbps) or above.

The operators will strongly invest resources in order to acquire the new spectrum and deploy 5G infrastructure during next decade, with continuous evolutions to support the ever increasing network demands. The commercial, societal, industrial and economic benefits will take a few years more before they convert into a positive return on investment. Nevertheless, like previous mobile communication generations, it is expected that the immense demand for network resources will eventually outweigh the promises made by 5G today. The process of developing technological solutions for next generation (from the research laboratory to validation, standardization and integration) requires a significant amount of time, typically 10 years. The first stages of research often precede the application needs, and have always been required to be able to deliver future requirements.

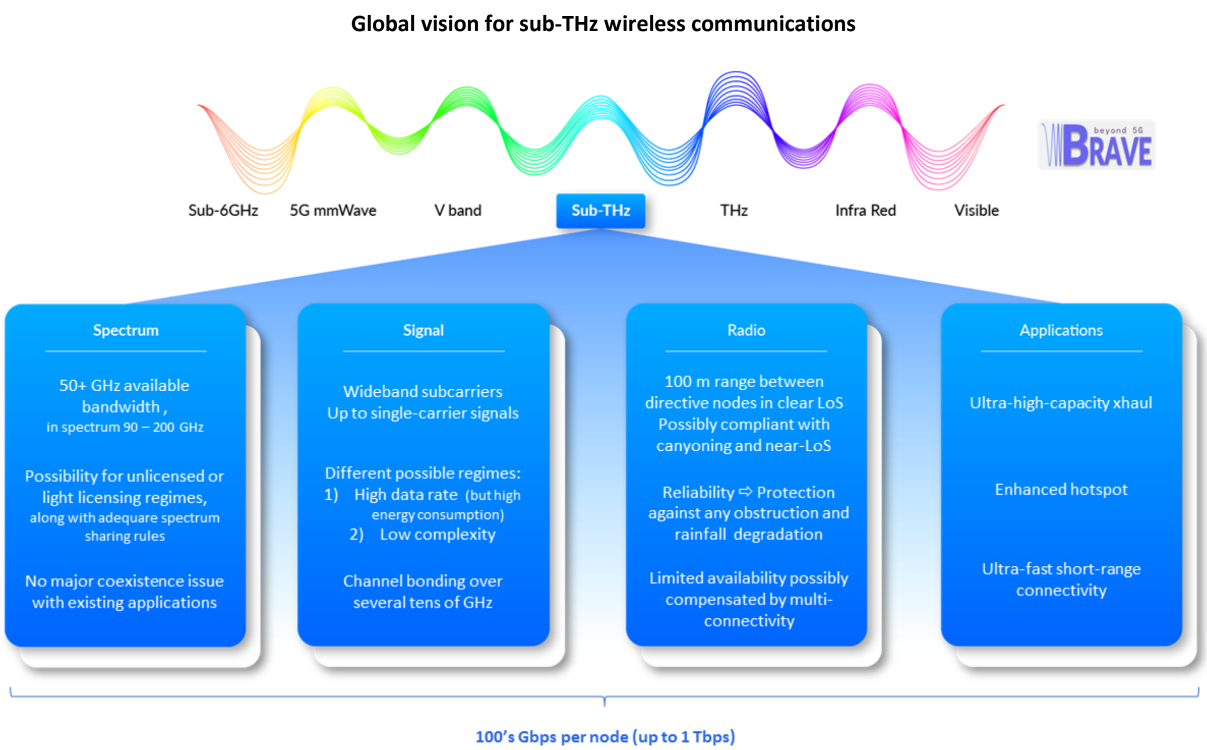
Applicable waveforms and perspectives, BRAVE is pioneering the investigations on sub-THz frequencies

Frequency bands above 90 GHz are attracting an increasing interest in the research community. They are already identified by key equipment manufacturers as one of the major enablers for future wireless communications to reach speeds and capacities 10 or 100 times higher than those that will soon be offered by the 5G technology.

Many essential innovations must be imagined and engineered before a system can effectively operate in the sub-THz frequencies: high-gain antennas; energy-efficient RF chain components; understanding of the wireless channel performance; suitable waveforms and coding; etc. The partners of the BRAVE project (Siradel, Centrale Supélec, CEA-Leti and ANFR) are among the pioneer investigators at these frequencies. They study the performance and constraints of the physical channel (propagation and RF chain) in order to develop and evaluate applicable sub-THz waveforms. A first step in this work was completed in January 2019 with release of the public deliverable D2.0. In addition to the technical research, the BRAVE project aims at providing concrete perspectives for the exploitation of the sub-THz spectrum, and encouraging the emergence of a devoted multidisciplinary community.

Interference management, scientific services protection… How the sub-THz spectrum may be exploited in future beyond-5G communications

The following figure illustrates how the BRAVE partners imagine the sub-THz spectrum to be exploited in future beyond-5G or 6G communication systems. More than 58 GHz of bandwidth has been allocated by international radio regulation for fixed or mobile land services between 90 and 200 GHz. Protection of scientific services such as radio-astronomy or meteorology, as well as satellite communications, should be easily managed by simple coexistence rules; the short range and/or strong directivity of sub-THz links is obviously an advantage here. As for lower frequencies, one can imagine a portion of the sub-THz spectrum is converted into free bands, along with relevant constraints on transmit powers, access protocols and utilization rate. This might allow for the emergence of many technologies and applications at short or very short ranges. Of course, other bands could be subject to an usual licensing regime for guaranteed protection against interference and guaranteed quality of service. As the propagation is strongly limited and high directivity antennas will often be employed considered, the light licensing regime is another viable option, where coexistence rules allow several actors to properly manage the interference risks and share the same resource; this may be appropriate for rapid backhaul deployments.



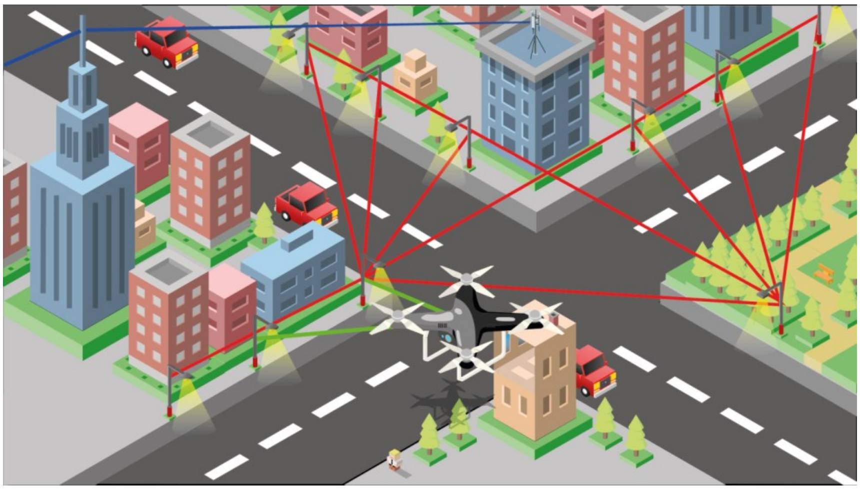
Single-carrier waveforms offer a key advantage over the traditional multi-carrier technologies that are used today in 3G, 4G and WiFi standards. They are consuming much less energy; and are compatible with the conditions that will generally be encountered in the sub-THz propagation channel (frequency flat). Depending on the data rate objectives and the energy capacities of the terminals, a different modulation scheme can be chosen. The BRAVE project investigates several techniques with various complexity levels, sensitivities, and efficiencies.

The sub-THz wave propagation suffers from many physical constraints: it is blocked or strongly attenuated by the presence of an obstacle, for example a wall, a tree or even a window; even for a clear propagation path, the losses are such that high-gain antennas are required, which means high directivity and alignment methodologies. These constraints are similar to those found in the millimeter-wave spectrum, but are accentuated. They strongly impact the range of potential applications.

Short-range communications, gaming, multi-user high-resolution VR… a few examples of sub-THz concrete applications

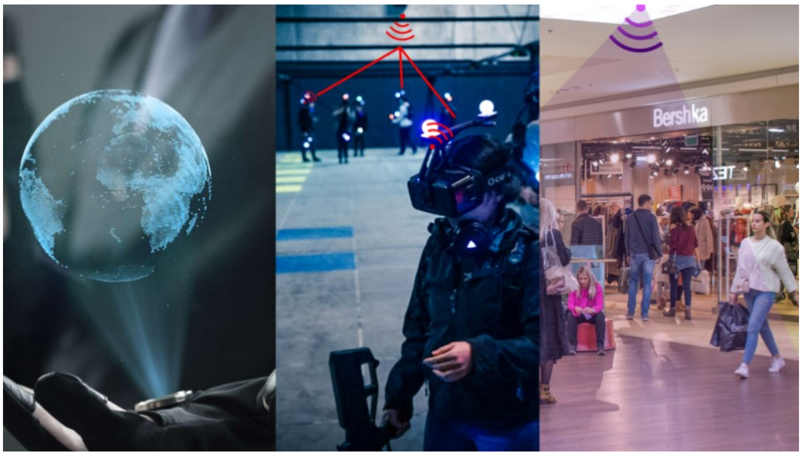
The applications considered into the BRAVE project meet two kinds of requirement: they have needs that will not be fully covered by 5G, with typically data rates greater than 100 Gbps per cell or per link; and they are compatible with the main constraints imposed by the sub-THz frequencies. Those applications have first been identified based on initial assumptions on the achievable data rates, power consumption and connectivity ranges. They have been classified into three families, as follows:

1) Ultra-high capacity x-haul, an indispensable evolution



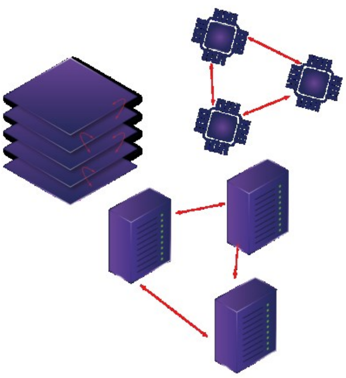
When the connection to the fiber network is too costly or unfeasible, e.g. for a deployment in a complex area such as an industrial site where cables have to be banned, for a drone relay, or a small-cell deployment into a fiber white area, the mobile xhaul network can be offered from broadband wireless links. Such solution is today relying on the mmWave spectrum. However the wireless xhaul can be a bottleneck for high-capacity networks with cells coordination, MIMO fronthaul, massive edge computing, or enhanced FWA services (Fixed Wireless Acces). Migration to higher frequencies is a natural evolution.

2) Paving the way to enhanced hotspots and digital experience



New applications such as multi-player virtual gaming, multi-user virtual entertainment, or holograms do require very high data rates for interacting with the cloud/edge computing resources, while they are confined in particular areas with limited mobility. We imagine other applications with same requirements will lately emerge from the high-resolution immersive capabilities or future digital technologies. The download of high-resolution videos at a kiosk connecting several customers is another relevant application that may be proposed within a hotspot like a mall, rail station hall, etc.

3) A real opportunity for ultra-fast short-range communications



Sub-THz is an opportunity for short-range static communications above 100 Gbps, such as to replace the bandwidth-limited copper wire into a chip or between chips, connect severs of a data center without any cable, or connect two close-by wireless devices for ultra-fast data transfer.

The viability of all these applications will be better qualified from accurate assessment simulations later in the project. **Read more on potential sub-THz applications and BRAVE proposed technologies [here](#).**

About BRAVE project

BRAVE is a collaborative research project started in January 2018, that aims at creating new physical-layer (PHY) techniques devoted to beyond-5G wireless communications. The partners (Siradel, Central-Supélec, CEA-Leti and ANFR) are designing new high-data-rate and energy-efficient waveforms that operate in frequencies above 90 GHz. Application to scenarios such as kiosks, backhauling, hotspots are assessed to evaluate the benefit of the proposed technology.

Funded by the French Research Agency ANR, the BRAVE project will go to its end in September 2021.

The consortium is combining skills from an industry (Siradel), an academic laboratory (Centrale-Supélec), a research institute (CEA-Leti) and a regulator (ANFR), which are all familiar with collaborative research and recognized in the field of wireless innovation. The partners bring complementary skills to efficiently tackle the different challenges of the project: regulation, signal processing, realistic modelling of the PHY-layer, and software-based evaluation.

About SIRADEL (France), project's leader institution

SIRADEL is an innovative high-tech company that helps cities to be better connected and sustainable. It provides solutions for wireless networks design and urban transformation planning based on a unique combination of technologies and know-how in the field of 3D city modeling, simulation, 3D analysis and visualization. Founded in 1994, based in France (HQ), Canada and China, a subsidiary of ENGIE since 2016, with 110 employees, SIRADEL operates with over 250 key account clients (telecoms operators and equipment manufacturers, municipalities, energy suppliers, transport companies, and national and international authorities) in more than 60 countries.

SIRADEL solutions optimize cost and performance of the connectivity networks (cellular 3G/4G/5G NR, IoT, WiFi, small cells, millimeter-wave access, backhaul, …), heating and cooling systems, smart lighting networks (LED, LIFI), geolocation-based networks (GNSS, indoors), assets for security (cameras, sensors) or smart mobility (autonomous vehicles, drones). It contributes to accelerate the convergence between wireless, fixed networks and all urban infrastructures and brings solutions to connect people, objects and assets. SIRADEL participates in several public and industrial research programs in future smart-cities design, aimed at the simulation and optimization of next generation urban infrastructures.

About Centrale Supélec (France)

CentraleSupélec is a public institution under ministerial charter, devoted to the sciences and engineering. This charter is shared between the Ministry of Higher Education, Research and Innovation, and the Ministry of Economy, Industry and Digital Technologies. CentraleSupélec was officially established on January 1st, 2015, bringing together two leading engineering schools in France; Ecole Centrale Paris and Supélec.

CentraleSupélec research center is composed of 17 laboratories and research teams which run in co-operation with major national research centres ; 1 research federation in mathematics ; 1 research institute with EDF ; 4 international laboratories with China, Canada, The United States and Singapore ; 1080 staff including 300 faculty researchers, 65 full-time researchers, 600 PhD candidates, 70 postdoctoral students, and 145 administrative and technical staff ; and 17 research chairs.

The SCEE (Signal, Communication & Embedded Electronics) research group that contributes to the BRAVE project belongs to CentraleSupélec campus of Rennes.

About LETI (France)

As one of three advanced-research institutes within CEA Tech, Leti serves as a bridge between basic research and production of micro- and nanotechnologies that improve the lives of people around the world. It is committed to creating innovation and transferring it to industry. Backed by its portfolio of 2,800 patents, Leti partners with large industrials, SMEs and startups to tailor advanced solutions that strengthen their competitive positions. It has launched 59 startups. Its 8,500m² of new-generation cleanroom space feature 200mm and 300mm wafer processing of micro and nano solutions for applications ranging from space to smart devices. With a staff of more than 1,900, Leti is based in Grenoble, France, and has offices in Silicon Valley, Calif., and Tokyo.

CEA Tech is the technology research branch of the French Alternative Energies and Atomic Energy Commission (CEA), a key player in innovative R&D, defense & security, nuclear energy, technological research for industry and fundamental science, identified by Thomson Reuters as the most innovative research organization in the world. CEA Tech leverages a unique innovation-driven culture and unrivalled expertise to develop and disseminate new technologies for industry, helping to create high-end products and provide a competitive edge.

About ANFR (France)

ANFR (Agence nationale des fréquences) is the French governmental institution that is responsible of the RF spectrum management: spectrum planning, frequency allocation, coordination of frequency assignments, control and international negociations. Within the project, ANFR is providing assistance in understanding the spectrum regulation constraints and opportunities.