# 6G WHITE PAPER ON CONNECTIVITY FOR REMOTE AREAS

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## 6G White Paper on Connectivity for Remote Areas

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# Executive Summary

In many places all over the world, rural and remote areas lack proper connectivity. This has led to an increasing digital divide. These areas may have low population density, low incomes, difficult terrain, and non-existent infrastructure, lacking a power grid, for example. This makes them less attractive places in which to invest and operate connectivity networks.

6G could be the first mobile radio generation that truly aims to close the digital divide. However, to do so, special requirements and challenges must be considered from the beginning of the design process. The aim of this white paper is to discuss requirements and challenges and indicate the related identified research topics that must be solved in 6G.

This white paper first provides a generic discussion, illustrates some facts, and discusses targets set in international bodies for rural and remote connectivity and the digital divide. The paper then delves into technical details, i.e. into the solutions space. First, a background overview is provided, followed by a closer elaboration of individual elements, i.e. terrestrial backhaul networks, terrestrial backhaul solutions, non-terrestrial solutions, the need for local operations, and frequency spectrum issues. Each technical section ends with a discussion and then lists the highlights of the identified 6G challenges and research ideas.

The following list provides a high-level overview of the observed challenges that must be addressed in 6G remote area research.

### High-level view of observed challenges

- The digital divide is increasing, and it is most acute in rural and remote areas.
- The solution must be affordable and provide sufficient data rate and availability. Furthermore, it should be easy to use and adaptable to different cultures.
- 6G could be the first mobile connectivity generation that aims to close the digital divide. To do so, it needs to concentrate on requirements and challenges in rural and remote areas from the beginning of the design cycle.
- Affordable and sufficient service (data rate and availability) solutions do not call merely for technical solutions but for novel regulation and cooperation between various stakeholders, notwithstanding the financing challenges.
- Technically, it uses mobile cellular solutions in places where people live and work (“digital oases,” as we call them) and various backhaul solutions including large cells, relay technology, and satellite technology. All solutions should target affordability and sufficient service, which may differ from targets set for new high data rate solutions for high-population urban areas.

## About 6G white papers (2020 edition)

This white paper is one in a series of 6G white papers in 2020 published in 6G Research Visions series. The list of papers is as follows (including publication number in the series). White Paper on 6G Drivers and the UN SDGs (No. 2); White Paper on Business of 6G (No. 3); 6G White Paper on Validation and Trials for Verticals towards 2030's (No. 4); 6G White Paper on Connectivity for Remote Areas (No. 5); White Paper on 6G Networking (No. 6); White Paper on Machine Learning in 6G Wireless Communication Networks (No. 7); 6G White Paper on Edge Intelligence (No. 8); 6G White Paper: Research Challenges For Trust, Security And Privacy (No. 9): White Paper on Broadband Connectivity in 6G (No. 10); White Paper on Critical and Massive Machine Type Communication Towards 6G (No. 11); 6G White Paper on Localization and Sensing (No. 12); White Paper on RF enabling 6G - opportunities and challenges from technology to spectrum (No. 13).

These white papers are collective efforts of interested contributors from all over the world. They were initiated by 6G Flagship[1] program led by the University of Oulu in cooperation with the 6G Wireless Summit[2].

[1] ***https://www.oulu.fi/6gflagship/***
[2] ***https://www.6gsummit.com/***

# Introduction

Today, many rural and remote areas in developed areas around the globe lack reliable high-quality Internet connectivity. Internet access and especially broadband connectivity is even more challenging in developing countries. Indeed, roughly half the world population remains without Internet connectivity, causing a sharp digital divide. Deficiencies in rural connectivity restrict the use of Internet services and the adoption of new technologies. This severely affects well-being and economic development in rural and remote areas.

Mobile radio technology generations have increased data rate (bits per second, bps) in each generation, as well as a total system throughput. Despite the massive potential, rural and remote areas remain largely unserved or poorly served. One of the essential reasons is low expected revenue, calculated as average revenue per user (ARPU), which reduces companies' willingness to invest in these areas [1].

Ending digital inequality calls for changes in investment support strategies and policies, as well as in regulation and technology development, to create affordable solutions capable of delivering a comparable quality of service (QoS) in rural areas to that in urban areas.

6G shows major potential to become the first generation to solve global connectivity challenges and dismounting urban-rural injustices as a response to the United Nations' (UN's) sustainable development goals (SDGs) [2]. A reliable mobile network designed to provide coverage in remote and rural areas can bring billions of unconnected or poorly connected inhabitants, professionals, and entrepreneurs into the information era. High-quality broadband access to applications and services, with connectivity for humans and machines, can revolutionize business processes and value chains in rural and remote areas, bringing new opportunities for both people and businesses. Toward 2030s, 6G connectivity will be able to serve the needs of individuals, households, businesses, governance, and machines.

This white paper addresses visions of rural and remote area connectivity to be realized with 6G solutions, with a focus on wireless radio technologies. The ultimate goal is to narrow the digital divide as much as possible with mobile technologies.

## Key facts

In 2018, 55 percent of the global population lived in urban areas [3]. In the same year, 67 percent (5 billion) of the world population of 7.6 billion had a mobile broadband subscription; only 3.9 billion had an Internet subscription [4], leaving 3.7 billion unconnected. The leading broadband use cases globally are video, fast access to websites (most of them content-heavy), and downloading of large software files (games, updates, etc.) [5]. In most cities throughout the world, throughput is 100–1000 Mbps with fiber access, or 50–500 Mbps with 4G/5G access. However, in rural and remote areas with low population density or low ARPU, the leading use cases are unfeasible, because they require at least 2 Mbps throughput for a good user quality of experience (QoE). For example, typical throughput in rural areas in the USA and Europe is approximately 0.5–1 Mbps using lines or 3G/4G. In rural India and Africa, on the other hand, typical throughput is as low as 20–200 kbps.

In 2018, the UN Broadband Commission for Sustainable Development adopted new targets aiming to connect the 50 percent of the world that remains unconnected and to curb the increase in the digital divide. One of the targets was to make entry-level broadband service affordable in developing countries at less than 2 percent of monthly gross national income per capita [4]. In rural areas in Europe and the USA, reasonable costs per user are estimated to be 30–70 USD/month.

### Characteristics of remote area connectivity

#### Connectivity

**Connectivity:**
**Access to internet services via fixed wired (fibre etc), fixed wireless (satellite etc) or mobile wireless (4G, 5G etc.)**

**Broadband:**
**Download speed at least 256 kbps*.**

#### Remote areas

**Remote areas:**
**Remoteness, with respect to connectivity, is caused by geographical distance from urban areas and base stations, difficult terrain, and lack of infrastructure, especially fibre, power grids and roads. Connectivity may be needed for unserved villages, farms, forests and mines, among others, but also for ships out on the sea and planes in the air.**

**Rural areas can be divided into three categories** with respect to remoteness, density and access to a city: rural inside metropolitan areas, rural outside but in close proximity to metropolitan, and rural remote. A village is categorized as rural remote if 50% of its population does not have access to a city within a 60-minute drive.**

*** OECD model survey, 2015 ** OECD Rural 3.0 policy**

#### Internet connectivity levels

**Major connectivity limitations**

**Unserved:**
**Total lack of available internet or voice services.**

**Poorly served:**
**Access and usage gaps for both individuals and businesses result from a limited choice of available internet services, high costs of use, low speeds, and poor quality of service (QoS) which restrict the use of more bandwith-intensive services, some of which may be core services such as health care and banking. Access can also be limited e.g. outside the residence or place of business.**

**Potential for enhanced connectivity**

**Underserved:**
**Insufficient capacity during peak hours, resources not optimized for user and community composition, securing of critical and internet-intensive business activities.**

**Unused potential:**
**User-related usage gaps include limited digital literacy and skills , and lack of knowledge on the broadband solutions available in the geographic area. Major potential in existing and evolving technologies, e.g. reuse of infrastructure such as TV towers and possibilities for connecting remote communities in parallel with railways, highways, roads and ports for purposes of autonomous fraffic.**

**Figure 1: Characterization of remote areas and a classification of connectivity problems.**

In rural areas in India, Africa, and Brazil, reasonable costs to reach many people are estimated to be 3–10 USD/month per user.

## Targets

The key requirement for rural and remote areas in the next ten years should be to provide at least 10 Mbps throughput. This will allow everyone to have similar access to today's in many urban areas [6]. As a benchmark, the European Commission has set the target (details below) that all households should have at least a 100 Mbps connection, gradually increasing to 1 Gbps. The download speed is usually of interest in these ranges, but this is expected to change in the future, because virtual and augmented reality, as well as video services (e.g. in e-health), also increase uplink speed requirements.

The European Commission adopted a strategy on "Connectivity for a European Gigabit Society" in September 2016 which sets a vision of Europe where "availability and take-up of very high capacity networks enables the widespread use of products, services and applications in the Digital Single Market." Broadband Europe[3] promotes this vision and policy actions to turn Europe into a gigabit

[3] Source: *https://ec.europa.eu/digital-single-market/en/broadband-europe*

society by 2025. Three main strategic objectives are included in this vision:

1. Gigabit connectivity for all the main socioeconomic drivers.
2. Uninterrupted 5G coverage for all urban areas and major terrestrial transport paths.
3. Access to connectivity offering at least 100 Mbps for all European households.

In addition, 5G connectivity should be available in at least one major city in each member state by 2020 at the latest. The previous broadband objectives for 2020 were to supply every European household with access to at least 30 Mbps connectivity and to provide half of European households with connectivity rates of 100 Mbps. The European broadband map[4] gives political decision makers as well as private investors the opportunity to monitor the progress made in the deployment of high-capacity networks and the quality of broadband services in Europe.

The Broadband Commission for Sustainable Development—a joint effort of the International Telecommunication Union (ITU) and the United Nations Educational, Scientific and Cultural Organization (UNESCO)—has set seven ambitious targets for 2025[5] aimed at connecting everyone, everywhere:

1. By 2025, all countries should have a funded national broadband plan or strategy, or include broadband in their universal access and service definition.
2. By 2025, entry-level broadband services should be made affordable in developing countries at less than 2 percent of monthly gross national income (GNI) per capita.
3. By 2025, broadband-Internet user penetration should reach:
    a) 75 percent worldwide;
    b) 65 percent in developing countries;
    c) 35 percent in least developed countries.
4. By 2025, 60 percent of youth and adults should have achieved at least a minimum level of proficiency in sustainable digital skills.
5. By 2025, 40 percent of the world's population should be using digital financial services.
6. By 2025, the non-connectivity of micro, small, and medium-sized enterprises (MSMEs) should be reduced by 50 percent by sector.
7. By 2025, gender equality should be achieved across all targets.

Target 2 will particularly assist lower income groups in developing and least developed countries to gain connectivity; Target 6 aims to solve the current challenge of MSMEs that have lower levels of connectivity than large enterprises in the same sectors.

## Previous and related work

From the technology perspective, the survey in [7] provides an excellent overview of the technologies discussed in this white paper and its sister white papers. Interested readers should use this for more detailed technical descriptions. 6G technology visions are discussed in [8], and visions in general in the first 6G white paper [9]. Remote area connectivity in Arctic areas was considered by the Arctic Council in its two task forces on Arctic communication that have reported their outcomes in [10] and [11], focusing on needs, challenges, and solutions. Related efforts are ongoing in IEEE Future Networks, especially in the "Connecting the Unconnected" INGR group[6]. Finally, indigenous people have considered connectivity and provided some recommendations in the 2019 "Indigenous Connectivity Summit Policy Recommendations,"[7] e.g. to use the unused spectrum in remote areas for their benefit.

The Organisation for Economic Co-operation and Development's (OECD) rural 3.0 policy[8] demonstrates how advances in communications technologies and digital literacy can overcome the challenges of distance through ten key technology areas driving rural change. During the next ten years, advanced communications techniques can ensure reliable and high-quality broadband connection for both individuals and businesses, enabling the use of Internet-based digital services, improving the teleworking experience, and enhancing the efficiency of rural businesses. However, access to high-quality broadband alone is not sufficient. Human capital will also need to adapt to the changing technologies, while rural areas will need high-quality public services and improved infrastructure—well-maintained airports, roads, and ports—to facilitate accessibility and increase attractiveness.

The OECD's digital economy paper, "Bridging the Rural Digital Divide,"[9] discusses the challenges of broadband accessibility gaps, good practices for bridging them, and

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[4] *https://www.broadband-mapping.eu/*
[5] 2025 Targets: "Connecting the Other Half" *https://www.broadbandcommission.org/Documents/BD_BB_Commission_2025%20Targets_430817_e.pdf*
[6] *https://futurenetworks.ieee.org/roadmap*
[7] *https://www.internetsociety.org/wp-content/uploads/2020/01/2019-ICS-Policy-Recommendation.pdf*
[8] *https://www.oecd.org/rural/rural-development-conference/documents/Rural-3.0-Policy-Highlights.pdf*
[9] *https://www.oecd-ilibrary.org/science-and-technology/bridging-the-rural-digital-divide_852bd3b9-en*

approaches for measuring the quality of service offered in each rural or remote area. A focus on download speeds is not sufficient, the paper notes, because individuals living in rural or remote areas are increasingly becoming producers of content who must also be able to share and create online content while benefiting new enablers such as cloud computing and big data. The paper underlines the importance of tailored targets for broadband availability that take into account the differing capacity requirements, depending on the varying number of service users and the composition of rural communities—residential, business or anchor institutions. The latter includes hospitals performing sensitive activities such as telemedicine, and therefore requires more intense capacity in terms of bandwidth and reliability.

The OECD's model survey on "ICT Access and Usage by Households and Individuals" and the OECD model survey on "ICT Usage by Businesses," both revised in 2015, offer a practical framework for evaluating broadband adoption and barriers to optimal connectivity. Data collected from individuals focuses on a wide array of relevant issues, including the type of Internet and mobile connection; type, frequency, and intensity of Internet-based activities; and level of satisfaction and perceived obstacles related to access and activities. For example, reasons for not having access to the Internet include motivations such as cost of equipment; cost of access; Internet services unavailable or very poor in the area; lack of confidence, knowledge, or skills in using the Internet; and privacy or security concerns. Difficulties experienced with mobile connectivity include difficulty in obtaining information on the cost of Internet access; unexpectedly high bills (e.g. due to roaming); difficulties with mobile network signal (unavailability of broadband or low speed); and difficulties in setting or changing parameters for Internet access (e.g. switching to WiFi, activation of location-aware applications, or activation of Internet access).

Remote and rural connectivity is an important study item in different countries around the world. There are therefore various current (or just finished) research projects on the topic. We have identified, for example, the EU–Brazil 5G-RANGE project , the UK 5G Rural First project, and the EU ONE5G project.  In the Nordic region, the Basic Internet Foundation   in Norway is a superb example of a focus on bridging the digital divide around the globe and addressing the problem of backhaul in both developed and developing countries. It has developed several solutions for remote areas and villages, and has already deployed them in Norway, Germany, and several countries in Africa.

## Relation to other 6G white papers

This white paper has strong relationship with white paper "6G Drivers and UN SDGs" [12] since that discusses the goals why improved remote area connectivity is needed. Other strongly related white papers are "Broadband Connectivity in 6G" [13], "White Paper on RF enabling 6G - opportunities and challenges from technology to spectrum" [14] and "Business of 6G" [15]. The first one discusses broadband technology that could be utilized also in remote areas, the second one handles spectrum issues that are relevant also in remote areas and the third one discusses business opportunities and models, and remote area is certainly one business case though not highly present therein.

[10] ***http://5g-range.eu/***
[11] ***https://www.5gruralfirst.org/***
[12] ***https://one5g.eu/***
[13] ***https://basicinternet.org/***

# Playground

Connectivity in remote areas will have a significant impact on people's lifestyle, business opportunities, and society at large. This will reduce the digital divide and improve the state of healthcare, education, transport, agriculture, energy, manufacturing, and employment. For example, distance learning and interactive teaching enabled by a broadband connection will improve the quality of education. Services such as e-agriculture and weather forecasting may help to improve productivity in agriculture and minimize losses. The future may also see popular digital or digitally enabled services in remote areas that we cannot presently imagine, but that have their own connectivity requirements. A currently imaginable example is increased usage of virtual and augmented reality in healthcare that may require high-speed two-way connectivity.

People often live and work in concentrations that we call digital oases in this white paper. These oases could be served using regular cellular technology, e.g. 4G, 5G, and WiFi. However, they may be away from main roads, outside electricity grids, or lack communication fibers. People will need robust, easy-to-use, and secure devices to connect in their oases and elsewhere. Maintenance of oasis equipment should be simple. People may be poor, so the expected ARPU would be very small. New and more efficient operation models may therefore be needed to run these connections. Furthermore, user devices should be inexpensive. Edge computing and slicing concepts may offer tools to use possibly expensive and perhaps limited backhaul efficiently, e.g. by caching and allowing traffic prioritization based on local needs. These may also be valuable tools for handling possible high variations in data rate requirements, e.g. between working and off-work hours.

Oases must be connected to the global Internet using backhauls. Sea and land cables/fibers, microwave links, and satellites and other non-terrestrial network (NTN) elements are current solutions, although they are not viable everywhere and/or for everyone. Global and economically feasible solutions are desperately needed. Newly emerging low Earth orbit (LEO) satellite systems offer an interesting global opportunity that will be followed with great interest, in addition to current and new geostationary orbit (GEO) and medium Earth orbit (MEO), as well as highly elliptical orbit (HEO) satellite systems, which offer local (although sometimes wide-area) coverage. Transportation passages connecting oases to other hubs also need connectivity, because continuous access is reality in many passages and should also be so in remote area passages. It should be remembered that polar regions are in a different situation, because GEO satellites do not cover them, meaning alternatives are urgently needed.

People sometimes tend to move and work around oases in difficult environments such as mountain valleys, and coverage is also needed in such situations. Direct user device access by satellite systems or large cells is a potential solution, but the current usage cost and relatively low data rates are the main limiting factors along with the lack of coverage. Ships and airplanes operating even in more remote environments need connectivity both for operation, maintenance, and reporting and for staff and passengers.

Frequency regulation in remote places (often) follows nationwide rules. However, more flexibility could easily be allowed, because many frequencies are actually unused in remote locations. The permitted transmit power can be increased to extend range in sparsely populated areas, with negligible health effects while delivering significant cost savings. It seems there is a need for two sets of regulations, one for urban areas, the other for remote and rural areas. If nationwide operators are unwilling to operate in oases, new local or micro-operators are perhaps needed. As it would be wise to use the same device everywhere, national roaming or similar solutions should be allowed. Billing aspects are also of interest in this respect.

We should not forget special needs like safety and rescue missions, which are naturally of interest and would benefit from improved connectivity in remote areas, assuming that new systems could fulfill the authorities' security, availability, and robustness requirements. Furthermore, (environmental) sensing and production-related machine-to-machine—Internet of Things (IoT)—communications are an emerging and often needed trend. Finally, low power consumption and smart usage of materials and resources, as well as sufficient lifespan and recyclability, are certainly factors that must be considered during development processes.

Communication systems are not standalone solutions but belong to the wide technology spectrum in oases. This may affect the availability of communication resources. For example, power generators for base stations (BSs) could be part of the local power grid, and the availability of power for communication may vary, meaning its transmission capabilities change. These power grids are also needed to charge connectivity and other devices.

It is important to understand local culture and ensure that the community is involved and trusts those offering connectivity services. This is particularly true in the developing world. Solutions to security and authentication should be aligned with the capacity of people living in remote areas, who are sometimes local tribespeople, to absorb technologies. Along with the technology key performance indicators (KPIs) such as bandwidth, latency, jitter, security, and resilience, new KPIs reflecting the increase in economic growth, education, health, gender equality, digital literacy, happiness index, and others in unserved/underserved remote and rural regions should therefore be considered in 6G network design.

In the remainder of this white paper, we attempt to envision solutions to these problems and raise key challenges and research questions around the topic. Ultimately, economic factors, as well as nations' and companies' ambitions, will show what could appear in the 2030s – in the 6G era.

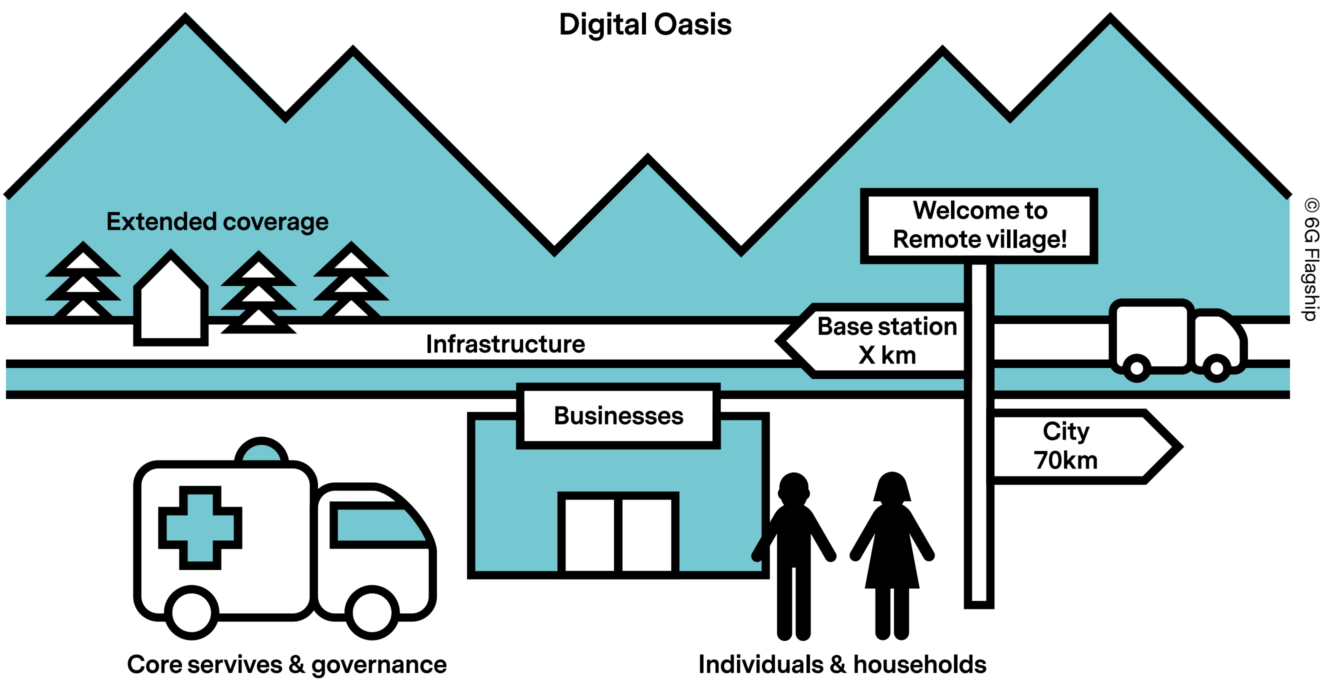


**Figure 2: An illustration of the playground in this remote area 6G white paper**

### High-level view of observed challenges

- The digital divide is increasing, and it is most acute in rural and remote areas.
- The solution must be affordable and provide sufficient data rate and availability. Furthermore, it should be easy to use and adaptable to different cultures.
- 6G could be the first mobile connectivity generation that aims to close the digital divide. To do so, it needs to concentrate on requirements and challenges in rural and remote areas from the beginning of the design cycle.
- Affordable and sufficient service (data rate and availability) solutions do not call merely for technical solutions but for novel regulation and cooperation between various stakeholders, notwithstanding the financing challenges.
- Technically, it uses mobile cellular solutions in places where people live and work (“digital oases,” as we call them) and various backhaul solutions including large cells, relay technology, and satellite technology. All solutions should target affordability and sufficient service, which may differ from targets set for new high data rate solutions for high-population urban areas.

# Wireless Terrestrial Mobile Radio Solutions

In this chapter, we focus on wireless terrestrial mobile radio solutions to deliver wireless connectivity or Internet access in rural and hard-to-reach areas.

Mobile terminals also seem to be the last-mile solution in the near future (also in the 2030s) to provide all kinds of connection in areas that lack fixed connections. Consequently, future mobile solutions should be affordable. The cellular infrastructure and mobile terminal technology should be inexpensive, and usage (along with backhaul costs) should also be cost effective (or subsidized somehow), so people in low income areas can use them. To achieve this target, along with constant improvement in the 6G data rate solution, a separate and more inexpensive solution may be needed with unified device types. Meanwhile, these oases serving mobile solutions should opportunistically use all available backhaul services.

Some oases (and relay stations) are outside power grids. They must therefore rely on refueled generators or renewable energy such as solar, wind, and water. Hence, low power consumption is a development driver, and careful system optimization based on power availability and usage may be needed. Furthermore, a power plant in an oasis may be part of a local power grid that is also used for household needs. This calls for a new type of (joint) resource optimization in both communication systems and power grids.

One of the immediate approaches to delivering wireless access to hard-to-access areas is to create extremely large coverage cells, also known as mega-cells. The deployment of new BSs for mega-cell creations for wireless access delivery is often associated with investment costs. These may be reduced if existing infrastructure such as high TV towers and buildings in hills/mountains, as well as new infrastructure such as tethered balloons, can be used. These high-spot transceivers can be used for both end-user access and to provide a backhaul connection to oases. They can also serve as relay stations in a microwave link chain. The future 6G system should support such multipurpose use and large coverage, which may require some investigation. In addition, suitable antenna technology may require some research attention to be paid to 6G frequencies.

Another pillar in the domain of terrestrial network applications for wireless access delivery in hard-to-reach locations is the utilization of "moving platforms," as well as the incorporation of the data-caching concept. It is envisaged that more and more future services will be non-human originated. Some will require real-time communications, but many IoT-type services have very relaxed delivery time requirements. In such cases, data can be collected using moving platforms. The class of moving platforms includes not only nomadic and movable base stations mounted on dedicated platforms, often (semi-) autonomous, but also vehicles, human users, unmanned aerial vehicles (UAVs), and other non-terrestrial platforms. These can also be used to distribute information and update software etc. at local nodes, enabling e.g. local caching-based services. Connectivity to moving platforms can be somewhat random, and the basic operation of nodes should not depend on them.

Slicing and caching can together play a major role in rural and remote connectivity, because local content creation and provision are envisioned. Moreover, the cacheable data in rural and remote areas may be higher compared with urban areas. The local community will therefore need to be empowered to create their own content and store it in a local server. Network slicing will enable resource-efficient realization of content-based connectivity and the creation of a differentiated service environment, including economic/free and premium/paid. Slicing and caching also help to keep local traffic local and offer other ways to avoid using a possibly limited and costly backhaul connection.

In many scenarios, allocated frequencies are used in urban areas and along main roads. Since frequencies may be allocated nationwide, some allocated frequencies remain unused in remote areas. Relaxing allocation rules and allowing local frequency usage, while keeping possible interference issues in mind, may facilitate the improvement of connectivity in remote places.

Connectivity is sometimes temporarily required in areas where it does not exist or is no longer available, e.g. due to a disaster. In this case, ad hoc networks are often needed, especially by "blue-light" authorities such as police officers, firefighters, and first responders. Deployable networks are such ad hoc solutions. They can be used to form independent local networks, but can also be connected to the Internet in many opportunistic ways. However, in developing 6G solutions for these issues, it is important to understand that public protection and disaster relief (PPDR) authorities may have specific requirements that are usually unnecessary in other uses. See [16] for a further discussion.

People sometimes need to be educated in and accept new technology. An example of how to do this is gaming and quiz apps developed for a particular rural region, where villagers self-learn the lessons on how to utilize the technology and devices through interactive audio-visual games and quizzes based on multiple choice questions.

### 6G challenges and research ideas

- Technology and standards for large-cell solutions.
  - Possible coexistence of 6G and TV signals in a TV tower.
- Power usage adaptation based on available power from a local power grid, taking other local power consumption into account.
- Tailoring caching and slicing for remote area use cases, both user and IoT.
- Mobile platforms, e.g. in collecting sensor data and supporting connectivity.
- More relaxing and flexible frequency regulations in remote places along with interference management issues.
- Deployable 6G networks, e.g. for emergency and authority use.

# Wireless Backhaul Solutions within 6G

Network deployment in rural areas (i.e. the most under-connected areas) is complicated by the varying degree of terrain that may be encountered when installing cables or fibers between cellular stations. Recently, the research community has also started investigating the feasibility of integrated access and backhaul (IAB), in which only a fraction of BSs connects to traditional fiber-like infrastructures, while the others wirelessly relay the backhaul traffic, possibly through multiple hops [17].

Although Long-Term Evolution (LTE) and LTE-Advanced already support BSs with wireless backhaul, future IAB developments foresee a more advanced and flexible solution, with multi-hop communications, dynamic resource multiplexing, and a plug-and-play design for low-complexity deployments. Additionally, a wireless backhaul enables non-terrestrial platforms, including satellites, to serve backhauling requests from on-the-ground terminals, thereby saving terrestrial resources for access operations. The importance of the IAB framework as a cost-effective alternative to the wired backhaul has been recognized by the 3GPP, within constant optimization over Releases 15 to 17 on architectures, radio protocols, and physical layer aspects for sharing radio resources between access and backhaul links [18]. Specifications may continue with enhancements and other scenarios in future, i.e. as part of beyond-5G standardization efforts.

IAB presents lower deployment costs and complexity compared to traditional networks with fiber backhaul and facilitates the site installation even where fiber may not be available (e.g. rural areas have a varying degree of terrain, making executing a cable or fiber buildout between cellular towers even more difficult and expensive). The potential of the IAB paradigm is particularly evident when wireless backhaul connections are realized at mmWave frequencies, thus exploiting a much larger bandwidth than in legacy sub-6 GHz systems. Moreover, IAB in mmWave offers the possibility to multiplex the access and backhaul data within the same frequency band, thereby removing the need for additional hardware and/or spectrum license costs.

Along these lines, the massive data rate requirements of the new 6G access technologies may require further growth of backhaul capacity. In this direction, utilizing the THz band becomes quite important. Traditionally, the lack of high-power compact transmitters and high-sensitivity receivers, combined with the high propagation loss resulting from the much smaller wavelength at THz frequencies, limited the communication distance in the THz band. However, major advances in THz device technologies [19] and tailored physical-layer techniques have recently made long-range THz communications a reality, not only for on-the-ground backhauls, but even for satellite communications [20]. Although many challenges accompany this spectrum, including the impact of atmospheric effects and the need for passive/active service coexistence, we expect THz IAB to be part of future 6G studies.

At the same time, it will be extremely important to design ad hoc scheduling procedures, to efficiently split the resources between the access and the backhaul and provide interference management, and avoid worse network performance in congested networks. Another important element to be considered in an IAB architecture will be the establishment and management of the network topology, including network formation, route selection, and resource allocation. In particular, the IAB topology should be dynamically adapted when a backhaul link is degraded or lost (to maintain service continuity) or when congestion arises [21]. Also, retransmission and packet reordering in case of multi-hop IAB connection retransmissions may introduce additional delays and negatively impact end-to-end performance.

Finally, it should be mentioned that the IAB architecture may require a certain number of optical fiber infrastructures to be already deployed. In this regard, fiber backhaul capacity can be increased if the existing wavelength division multiplexing based network is gradually migrated to an elastic optical network by technology upgradation at nodes, without a need for the expensive deployment of new optical fibers. Moreover, the rich power distribution network infrastructure should be leveraged to improve connectivity in remote regions without significant investment by using either the overhead fiber cable network of power grid companies or using cost-effective powerline communication technology, both narrowband and broadband. Likewise, road/highway lights could be opportunistically used whenever feasible.

Although this section was about IAB, other advances in microwave radio link technology are also welcome.

### 6G challenges and research ideas

- Advanced backhaul connections:
  - Via mmWave and THz frequencies, including novel antenna solutions.
  - Visible line and power line backhaul solutions.
  - Satellites, mega-cells.
- Flexible IAB application:
  - Scheduling procedures that dynamically split the resources between access and backhaul.
  - Efficient routing/path selection strategies, which are robust to network topology changes and end-terminal mobility, for the determination of the optimal backhaul path.
- Smart (re)usage of existing infrastructure.

# Non-Terrestrial Network Solutions

Satellites and high-frequency (HF) solutions are currently applied in very remote areas (sea, air, deserts) and are likely to be the case in their future versions. Non-terrestrial network (NTN) systems include satellite systems (SATCOM) at different orbits, high-altitude platforms (HAPS), UAVs, and balloons. NTN solutions may also serve other remote places and oases by providing direct user access or backhaul connection, or complementing terrestrial services. Ultimately, we should look for hybrid or integrated terrestrial and NTN solutions.

The benefits of NTN include [22]:

- *Communication resilience:* Non-terrestrial platforms enable wide connectivity coverage and guarantee seamless service continuity, e.g. in rural areas, or when terrestrial infrastructures are not available, as is the case at sea.
- *Energy-efficient connectivity:* Non-terrestrial nodes can be deployed on demand, implementing smart duty cycle control mechanisms, thereby reducing the operational and management costs of fixed infrastructures.
- *Resource optimization on parallel backhaul links:* Non-terrestrial platforms offer an additional and robust channel for backhauling operations, thereby saving terrestrial resources for access traffic requests. This also guarantees that on-the-ground terminals can find an alternate route to preserve the connection if terrestrial links are unavailable.
- *QoS enhancement through edge computing:* Air/spaceborne stations, including satellites, can host mobile edge cloud functionalities to support communication, computing, and storage operations for on-the-ground users to execute their cloud services
- *Communication on the move.* Satellites provide high-speed connectivity to individual in-motion terminals that cannot benefit from terrestrial coverage, such as on planes or vessels.

A disadvantage of existing satellite systems is the high cost of both user-terminal (e.g. within BSs) and satellite connection. Future solutions should address these and provide economically affordable solutions.

Efforts for improved capacity are ongoing in the satellite sector in both more traditional GEO/MEO orbits and emerging concepts in LEO/HEO orbits that also feature polar coverage. Some balloon initiatives also exist—see [7] for further details. Technology advancements that have made this possible include Gallium Nitride (GaN) technology, the emerging mass production of satellites, antenna arrays for tracking multiple mobile satellites and intersatellite (optical) links (ISL) for enhanced spaceborne routing, meaning that ground gateways are not always needed. Inter-satellite system connectivity may further improve the situation, as well as the inclusion of terrestrial systems in this system-of-systems. Free-space optical technology and other new radio frequencies, e.g. mmWave, may be used to connect satellites to their ground gateways with even higher data rates.

The integration of NTN with mobile terrestrial systems has been initiated as a 3GPP study item, with the expectation of reducing costs with common chips, in addition to other benefits. After identification of the possible challenges, 3GPP has started to solve these problems [23]. As the satellite system design lifecycle especially is rather long, it is anticipated that these 5G-based (Release 17 and 18) solutions will be in use in the early 2030s. 6G should include the NTN component in its design from the outset to avoid expending a lot of effort on this later. Integration is also considered also by satellite actors, e.g. in [24].

Among all innovations, the availability of multilayered networks [25], [26], i.e. orchestration among different aerial platforms operating at different altitudes, currently represents one of the most promising technological options for non-terrestrial systems, making it possible to obtain better spatial and temporal coverage. The service model envisaged here comprises two configurations. In the first arrangement, a single non-terrestrial platform operates in a "tower-in-the-air" configuration by which it relays data obtained from the ground station (uplink) to various service delivery platforms in the downlink. In the second configuration, a swarm/cascade of aerial stations is used as both relay nodes and service delivery devices for local users. LEO and MEO satellites, as well as HAPS, can be used together if the area to be covered is significantly large by combining multiple radio technologies in a single solution that is more robust and efficient than any individual approach. Despite current standardization efforts for the development of NTNs [23], the constant optimization of appropriate protocol design still calls for long-term research to overcome the larger propagation, coverage, and high mobility, and enhance service quality and service continuity. From the implementation perspective, a constellation to maintain ubiquitous service continuity, which may in turn be very difficult to install, is also required.

Moreover, to ensure the smooth commercial usage of the future integrated network, close cooperation among different operators with infrastructure sharing may also be needed. For example, core network construction by the terrestrial operator can be shared with satellite-based access for user equipment (UE) located in different regions. A unified set of services can be provided with adjustment per access based on radio access network (RAN) capability. Meanwhile, such a mechanism with a specific gateway is feasible for the integration between TN and NTN with either unified or different access techniques.

From the above discussion, although non-terrestrial networks are emerging as a key component of the future 6G telecommunication landscape, it appears various optimization remains necessary in further research.

### 6G challenges and research ideas

- From the standardization perspective, enabling the integration of NTN and TN (e.g. at the beginning of 6G design) including:
  - Enhancement of physical, access, and network layers addresses the challenges imposed by the different NTN channel profile, e.g.
    - dealing with the significant end-to-end propagation delay;
    - satellite-friendly signals (e.g. low back-off);
    - flexible design to achieve the concept of "routing" for the Internet of Space, including local connectivity via NTN;
    - the trade-off between coverage vs. data rate.
  - Enable MEC via NTN node.
  - Resource utilization optimization/sharing in hybrid systems, even if non-6G (non-3GPP) NTNs are used.

- Optimization of multilayered networks.

- From the implementation perspective, to enable the NTN with
  - efficient power amplifiers for satellites to boost their efficiency and improve link budget;
  - efficient (programmable) satellite platforms and stability to overcome the difficulty of maintenance and reduce costs during the lifetime of the satellite.

- Inexpensive NTN solutions/technology and affordable usage.

# Micro-Operators

Leading operators have thus far failed to provide sufficient connectivity for many remote places throughout the world. Recently, governments have either supported this or "directed" operators to cooperate in creating coverage. Despite these developments, new operational models may be needed to further increase the penetration of Internet coverage. The establishment of local networks without the direct involvement of national operators has become increasingly important in serving areas where operators see no business case. We call them local private networks or micro-operators in this white paper. This means a village or property owner could run its own network to provide connectivity in the area. Naturally, this has to be done according to regulations and rules, and depends heavily on the local availability of the spectrum. In remote areas, infrastructure construction may be supported by other bodies like private companies, governments, or international organizations. Furthermore, cooperation with leading operators should be guaranteed. Micro-operators who engage with the community and come from the same stock have a much greater chance of success, because they consider their local needs and can even leverage their infrastructure to reduce capital and operation costs to become profitable.

The potential of the micro-operator concept has been partially illustrated by its successful deployment in Peru to improve rural connectivity[14]. In this case, the micro-operator that deploys the network infrastructure and operates it in rural areas is called the rural mobile infrastructure operator (RMIO). Its infrastructure is interconnected to the mobile network operator's (MNO's) network core, and revenues are shared.

Certainly, many nations execute rather rigid frequency regulation, in which frequencies are often provided through nationwide auctions to one operator or several, indicating that micro-operation by non-MNOs is indeed impossible due to the lack of a spectrum for them. Once lighter regulatory requirements for such local micro-operators and a supportive government regime have proven beneficial, and if more flexible frequency use is allowed, the unused spectrum in remote areas can be utilized. However, if this is not an internationally agreed process, the market will be small, and devices will be expensive unless new flexible inexpensive radio platforms can be made available. Flexible frequency use means that interference control (in the spectrum) must be automated rather than manually executed. For a sustainable micro-operator ecosystem, issues such as maintenance, risk, resilience, interference, scalability, and power need to be considered, and these challenges can be most effectively and efficiently handled through community training and involvement.

Users in oases should also be allowed to join larger networks and vice versa. National roaming or a similar solution should therefore be ensured. Furthermore, sensible billing procedures are needed for micro-operators. In addition, ways of controlling traffic share require development. Local networks may have limited capacity, allowing a (large) number of visitors to completely block the system. Local needs must therefore be guaranteed. This can be managed by having a network slice for locals and visitors, and dynamically adjusting the bandwidth based on load, but guaranteeing locals their share if they need it. Finally, local communities should be able to manage the most important applications for them, e.g. favoring of e-learning and e-health services before video browsing to ensure possible limited backhaul can be used most efficiently. All this is in addition to keeping local traffic local

[14] 5G RANGE project, "Deliverable D7.1 -Exploitation, communication, dissemination and standardization—Part I," January 2019. http://5g-range.eu/.

and utilizing edge computing for caching (also to reduce backhaul usage) that should be available after 5G.

To ensure high QoS for the provided services, the operators and the local community should be sufficiently skilled to maintain and repair the equipment used in the deployed technology. They should view learning digital technologies as pathways to better employment and well-being for the community.

### 6G challenges and research ideas

- The entire local micro-operator ecosystem must be considered. It includes various aspects:
  - available frequencies: new flexible frequency regulation utilizing the unused spectrum in remote areas and allowing local operation;
  - national roaming (or a similar solution) to allow nationwide use of the service agreement;
  - a billing system;
  - maintenance and operation;
  - financing models;
  - dual use with government actors such as SAR, healthcare, education, etc.
  - coexistence and cooperation with leading operators.

# Radio Frequency-Related Issues

The radio spectrum is the lifeblood of the telecommunications market. The debate centers mainly on how this resource, despite being limited and naturally finite, can drive both urban and remote connectivity. The academic and industry communities have identified two generally accepted solutions to achieve the 6G promise of ubiquitous connectivity, either to allocate an additional spectrum through sharing/re-farming or introducing new frequencies mainly in the higher bands, which also increasingly involves sharing/re-farming. This is a joint effort between researchers, standardization bodies, operators, and regulators.

Nowadays, radio spectrum is exclusively and statically allocated to different wireless services, leaving a very limited spectrum for fixed frequency assignments. This has resulted in spectrum shortage resulting from the outdated spectrum management policy rather than physical scarcity [27]. A more flexible spectrum usage is preferred in future.

Sharing methods have been studied in the past, and some have even been applied. These efforts should be continued during 6G research and further developed. As this white paper highlights, techniques that ease operation in remote areas will be especially welcome. These include local micro-operators, cognitive radio networks, coexistence with sub-6GHz bands, and multi-tiered spectrum access methods.

Meanwhile, mmWave and THz bands can provide large chunks of the spectrum required to meet the extremely high throughput demands in 6G. However, these bands are very sensitive to molecular absorption and impose tight constraints in terms of line-of-sight propagation, with very limited penetration capabilities. On the positive side, these characteristics make mm and THz bands perfect for opportunistic spectrum reuse. Future research efforts may focus on the harmonious coexistence of users, because communications are short-range and highly directional, meaning interference can be contained by avoiding the transmit beams or simply by being located a few meters away. To attain this objective, novel beam management and power-level coordination schemes need to be designed. Unfortunately, the flip side of using these bands is that the required infrastructure investment is quite significant, and the operator must make difficult trade-offs between coverage, capacity, and cost.

### 6G challenges and research ideas

- A new and more flexible regulatory framework.
- Innovative incentive mechanisms to motivate the incumbents to share their underutilized or unused spectrum, especially in attractive frequencies such as the lower and mid bands. In this regard, infrastructure-sharing agreements between operators could be inspiring.
  - Adopting new business models and regulatory proposals for spectrum access frameworks that are technically feasible, commercially affordable, and support remote area connectivity.

# Summary

The goal of the white paper was to identify 6G research ideas as they relate to connecting remote areas. These ideas can be used to propose further 6G research and development to connect everyone on the planet, especially those in remote and rural areas who remain under-connected. With a primary focus on urban areas, the issues highlighted in this paper have not received the urgently needed attention. The ideas and challenges were summarized in each section. In summary, there is no shortage of excellent research ideas to serve remote areas. These research ideas span multiple stakeholders, from users to operators to regulators to content providers to local entrepreneurs.

The following figure illustrates the technical areas discussed in this white paper in the context of connecting remote and rural areas to achieve the vision of ubiquitous connectivity.

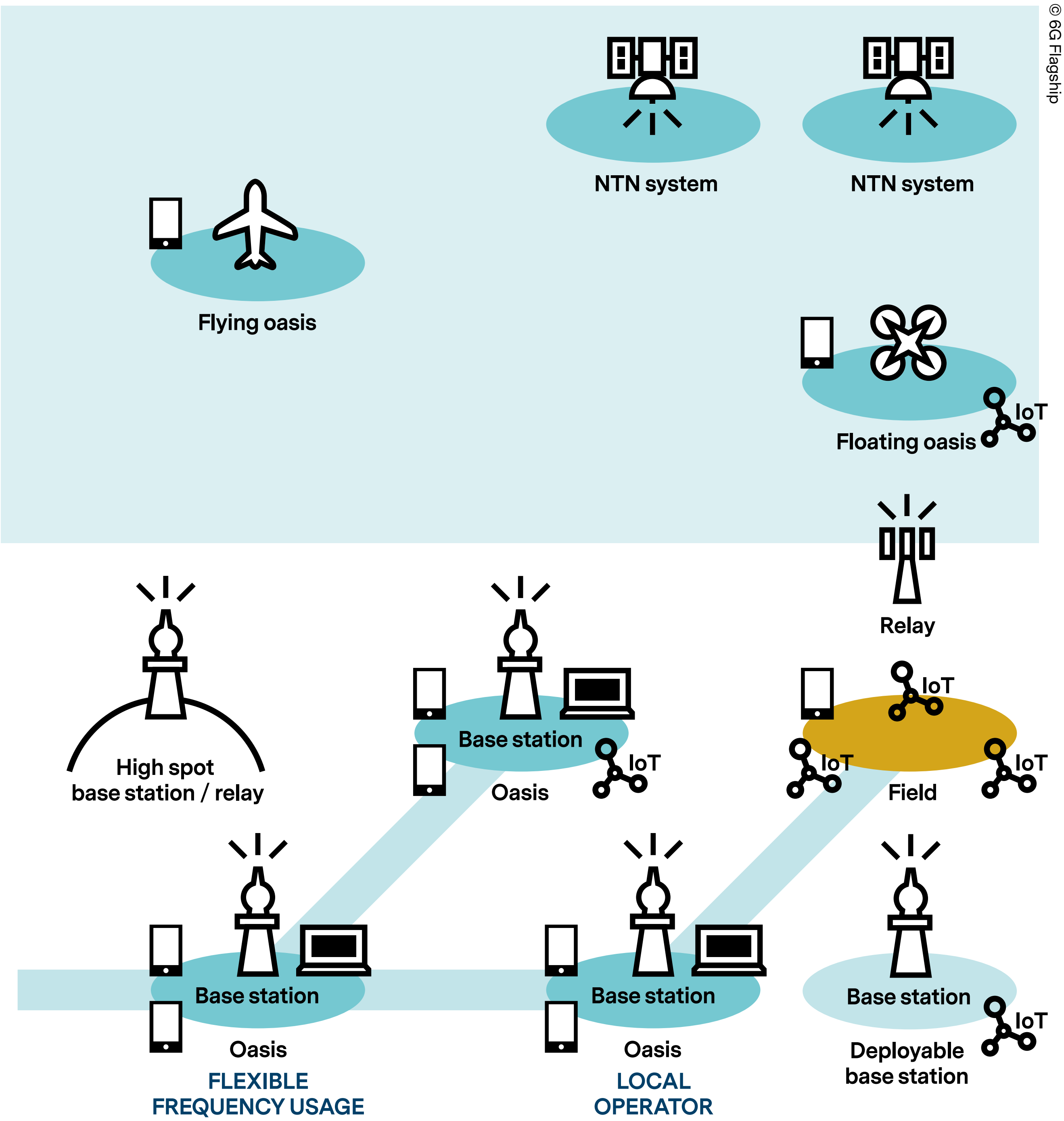


**Figure 2: An illustration of the playground in this remote area 6G white paper**

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