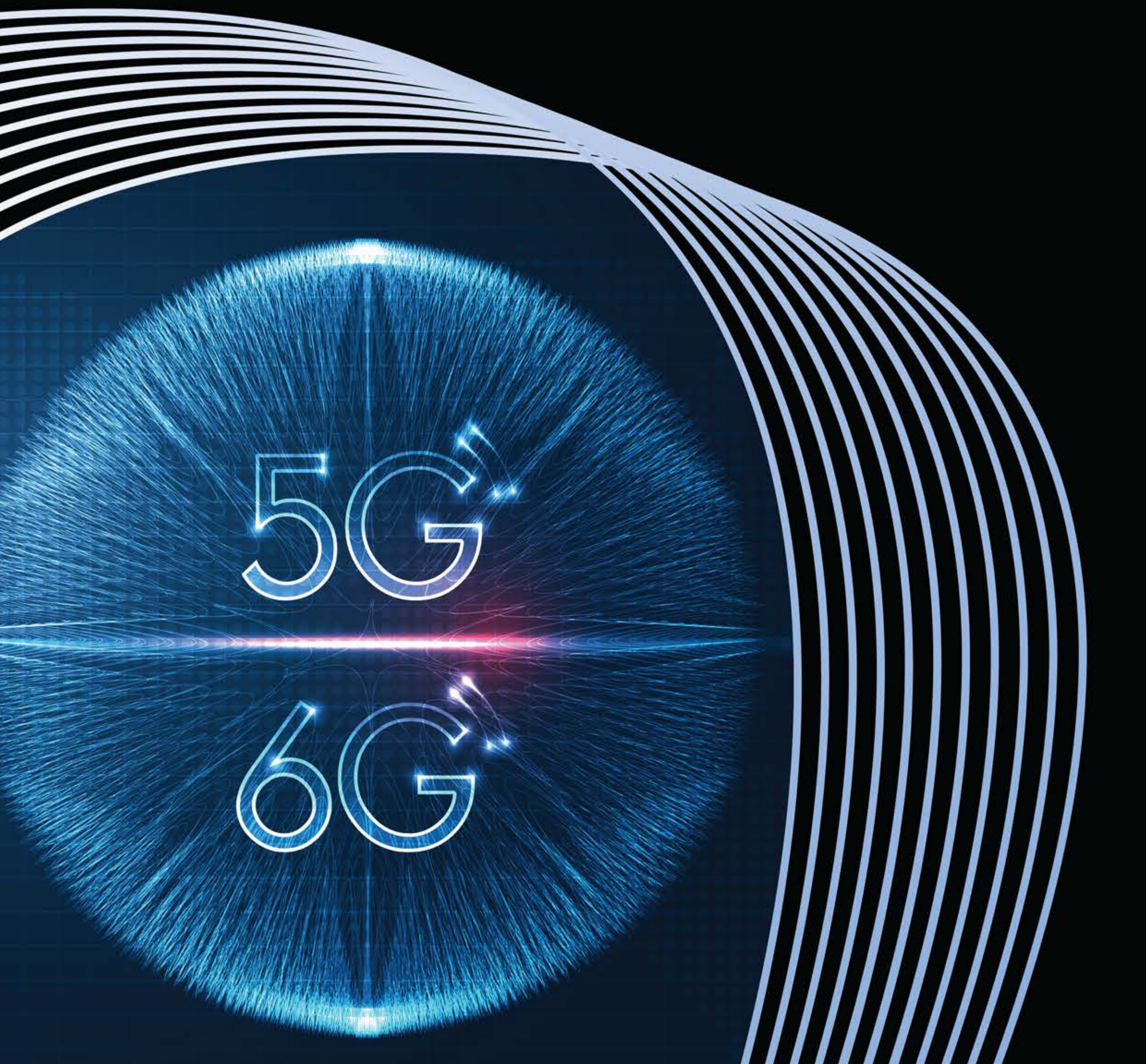
DOI: 10.57650/INNOVACTION/2023.02

02 Evolving invisible 5G small-cells to 6G smart radio environments



During the "Invisible 5G" project, it was possible to address the challenges of 5G network densification, with a particular focus on site-specific requirements in urban areas. Altice Labs has been pursuing 5G densification efforts and is laying the groundwork for 6G smart radio environments. The project introduced a novel concept of "invisible" 5G small cells that are designed to seamlessly integrate with existing urban infrastructure, such as lampposts and utility poles, rather than being traditionally placed on building rooftops. These small cells consist of two key modules: the Radio Unit (RU) and the antenna. One of the project's innovations involved the incorporation of Reconfigurable Intelligent Surfaces (RIS) to address issues like power consumption and interference. This makes the small cells highly versatile, and capable of advanced electronic beam steering (T-RIS – Transmit-RIS) to serve micro and macro-coverage areas. This unique hybrid solution, combined with urban integration, represents a significant paradigm shift in mobile communications. Moreover, this innovative approach not only enhances urban landscapes but also offers the potential for short-term adoption in a vast market. This can lead to increased exports in the mobile broadband sector, positioning Portugal as a product supplier alongside its service offerings. The project's evolution from 5G small cells to 6G smart radio environments, powered by RIS, holds great promise for meeting the increasing demands of mobile network deployments.

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Keywords

Invisible 5G; 6G; Smart radio environments; Small cells; Reconfigurable intelligent surfaces; T-RIS; R-RIS; Urban furniture

Introduction

The "Invisible 5G" project aimed to address the challenges associated with 5G network densification as a key driver for enabling 5G. It particularly focused on the challenges arising from site-specific requirements that bring unique challenges to the design and deployment of small cells in urban scenarios at a scale required for future 5G (and 6G) coverage and services. During the ramp-up phase of Portugal's 5G rollout, denser localized coverage will allow 5G networks to move closer to the end-user to support evolving communications technologies, which ultimately will help build smarter and more technologically advanced communities and infrastructures.

It is proposed a state-of-the-art, low-power, small-form-factor, highly concealed (or invisible), ruggedized, weather-proof, and easy-to-deploy 5G small cell. Invisible 5G small cells are, therefore, sought to be world-class and premium compact 5G small cells that are highly concealed and have high levels of integration with existing urban furniture, such as utility poles, lampposts, or even technical cabinets, reducing the need to deploy base stations on building rooftops and facades.

The evolution of 5G small cells into a 6G smart radio environment (which is powered by reconfigurable intelligent surfaces, or RIS) is a promising solution to meet the demand for increasing throughput in 5G and 6G mobile network deployments. Power consumption and two-tier interference issues are bottlenecks that hinder further developments in typical small-cell deployment. Thus, the rationale is to evolve invisible 5G small cells by integrating reconfigurable intelligent surfaces as either transmit (T-RIS) or reflective (R-RIS). In the former, T-RIS will enable advanced electronic and agile 2D beam steering, serving multiple users as a small base station while assisting the macro-coverage users in enhancing their radio coverage by anomalous reflections in an R-RIS configuration. The initial results of the proof-of-concept will also be presented. Such a hybrid T-RIS and R-RIS solution, combined with the high levels of urban integration in the street landscape, makes the evolved invisible 5G small cells a novel paradigm in the mobile communications sector and delivers a unique solution that is timely and topical. Furthermore, it has the potential for short-term adoption in an enormous market and, thus, to further leverage Portuguese exports in the mobile broadband arena as a product supplier other than services.

The paper is structured into seven sections, with an introduction followed by a focus on the need for 5G densification in urban areas and the specific challenges faced in Portugal. It then introduces the invisible 5G small cells and delves into Altice Labs' role in the densification race. The paper concludes by looking ahead to the future, exploring the transition to 6G technology and the integration of Reconfigurable Intelligent Surfaces in separate sections.

The need for 5G densification

The importance of 5G densification in urban areas

Sitting on the cusp of a new decade that is expected to be profoundly impacted by 5G, the fifth-generation wireless network standard is here. The national priority for many countries is to secure a 5G rollout as its spread is pivotal for the connected world. For the first time in mobile communications history, 5G will serve as the backbone of the fourth industrial revolution and, thus, the global pacesetter for the convergence of all connected technologies and bring this technology transformation to fruition in an economic and efficient manner.

It's important to mention that all benefits and capabilities that have been promised will be possible on 5G SA (Standalone) and not on the 5G NSA (Non-Standalone), that generally the telecom operators started to make available. It will still take some time before 5G SA becomes mainstream and achieve wider coverage areas.

Site-specific requirements and challenges

One of the fundamental changes that 5G introduces in the radio environment, is the need for cell densification in urban scenarios. This could be achieved from the combinations of frequency bands (a blend of low- and high-frequency spectrum) that 5G must use to yield its extremely high data rate (throughput), low latency, and ubiquitous coverage. In densely built-up areas where propagation through obstacles, such as buildings and trees, is an issue, operators need to densify their mobile networks with small cells. In the 5G age, it is less a "nice to have" and more of an operational "must-have" to achieve the quality of service (QoS) that consumers and enterprise customers expect.

Despite the slow take of both 5G regulatory issues and spectrum auctions, mobile network operators (MNO) are now referring to their radio usage heat maps to evaluate the geographical areas of high 4G usage to plan their 5G small-cell strategies. Deployment places like busy city centers, motorways and train routes, airports, and shopping malls are all candidates. Outdoor small cells come in many different shapes, sizes, and configurations. For instances, MNOs may want to do their recent investments on 4G (LTE) spectrum acquisition by using carrier aggregation to increase capacity. This implies using three, four, or five different licensed bands at the same time, and they may use multiple-input-multiple-output (MIMO) antenna technology for additional capacity. These requirements multiply the amount of RF (Radio Frequency) hardware at a site. A small cell is defined as a single geographic site and can be made up of radios, antennas, and other equipment. Outdoor small cells can differ from city to city, even street corner to street corner, depending on the requirements of the site, municipal jurisdiction, MNO, or subscriber population and mobility phenomena in the area. The site-specific requirements bring unique challenges to the design and deployment of small cells at the scale required for future 5G networks.

Ramping up 5G rollout in Portugal

The challenge of location means that small cells should be put in the available space, which may not be ideal for placing, e.g., MIMO antennae. Street furniture, used to define objects in public spaces that house small cells in boxes and are considered visually commonplace and acceptable to the public, such as utility poles, bus-stop enclosures, or any other street-level infrastructure that can house wireless equipment, offers highly effective tools to MNO in expanding their networks using small cells, distributed antenna systems (DAS), backhaul and other means to transmit and increase radio coverage to augment network densification. These small cells should be a miniature version of the traditional macro-cell, in the sense that radios and antennas should be somehow compressed into a low-power, easy-to-deploy radio device. Typically, small cells have a range from ten to a few hundred meters and can be incorporated into street furniture, as long as this is equipped with a power source for the radio equipment to operate, and can accommodate power, antenna, and associated fiber and other cabling equipment. This imposes stringent design requirements, and thus, good engineering is crucial to a successful small-cell deployment.

Additionally, the co-existence with e.g., traffic control, on the same traffic light utility pole or on a lamppost, limits the physical space available for small-cell radio equipment, more so as this is typically regulated by local municipality. Also, neighborhood residents will not accept an eyesore to get better radio service. So, pleasing concealment is of uttermost importance.

The concept of invisible 5G small cells

Small-cell concept

The primary objective of the "Invisible 5G" project was to tackle the challenges associated with the densification of 5G networks. This involved the development of compact 5G small-cell base stations designed to be virtually invisible, boasting high levels of concealment for easy deployment on street furniture. The core concept revolved around introducing innovative design solutions capable of seamlessly integrating the radio unit, antennas, and associated fiber and cabling equipment in a camouflaged fashion.

To achieve this, the project relied heavily on effective design and engineering strategies. These strategies encompassed the creation of custom protective casings for antennas, radio units, and infrastructure. The purpose of these casings was multi-faceted: to safeguard internal components from the rigors of weather and vandalism, ensure optimal signal transmission, simplify maintenance procedures, and seamlessly blend with their environment, rendering them inconspicuous.

Key features

According to the project requirements, the small cells in the "Invisible 5G" project were designed with the following key features in mind:

- **Concealed design:** the paramount objective was to achieve a high level of concealment. This was accomplished by seamlessly integrating the radiating systems, radio unit, and associated wiring within customized enclosures or boxes. This design allowed for a harmonious visual integration, ensuring that the small cells could blend into their environment, essentially going unnoticed once installed;

- **Easy deployment:** the small cells were engineered for easy and non-intrusive deployment. They could be quickly attached to existing infrastructure, such as public lighting poles, with minimal mechanical intervention. The solutions presented in the project were designed to be easily reversible, thereby protecting public assets while facilitating installation;

- **Small-form-factor:** the small cells were compact in design, achieved through the use of Altice Lab's Radio Unit, which had dimensions of approximately 352x235x120 mm^3. This unit incorporated all the necessary radio frequency electronics and hardware for connecting to the core of the 5G network. Custom antenna designs with reduced footprints and high modularity were also employed, making them adaptable to various deployment scenarios;

- **Heat dissipation:** in addition to their compact and low-power design, the small cells addressed heat dissipation concerns. The proposed solutions included techniques to increase the exposure of hardware components to outdoor air and an arrangement that facilitated natural air flow through convection, thereby managing heat effectively;

- **Ecologic solutions:** environmental sustainability was a crucial consideration in the development of these small cells. The project emphasized an environmentally responsible approach throughout the entire product lifecycle, from material sourcing to disposal. Recycled materials, specifically recycled tire-based compounds, were utilized for producing structural parts and some customizable casings. These materials were employed through additive manufacturing, reducing waste, and providing eco-friendly alternatives to traditional composite materials. The parts were mostly produced using a polymeric compound made of shredded end-of-life tyres and polypropylene (75%/25%). This approach aligns with the project's commitment to addressing environmental challenges in a creative and sustainable manner.

Overall, the "Invisible 5G" project aimed to deliver small cells that were highly concealed, easy to deploy, compact, efficient in heat dissipation, and environmentally friendly, making them a noteworthy advancement in the evolution of 5G network infrastructure.

Integration with urban furniture

The design project was structured around three distinct case studies, each characterized by unique visual and production requirements. This approach ensured that the outer casing could be easily adapted to the specific visual characteristics of each deployment location. Three primary integration and customization strategies were developed within the project:

A - The Standard casing

The Standard casing (**Figure 1**) was developed with the objective of being a compact, orientable, and economical solution for telecommunication poles or urban areas where the visual integration needs are less demanding.

A strategy of embedding the antenna into the technical access cover of the RU was used, making the final product as compact as possible and minimizing the wiring required between the RU and the antenna. This solution abuts the antenna in front of the RU, requiring the use of a unidirectional antenna, which was developed in the project, and which takes advantage of this characteristic to increase its efficiency from the point of view of signal emission.

The main parameter of urban integration in this scenario is the choice of the pole to be used and its location relative to the area where you want to have the best signal. At the same time, the integration of the antennas depends essentially on the choice of the most appropriate place for them to go unnoticed, intending with the adjustment and orientation system proposed to avoid the installation in points of greater visibility.

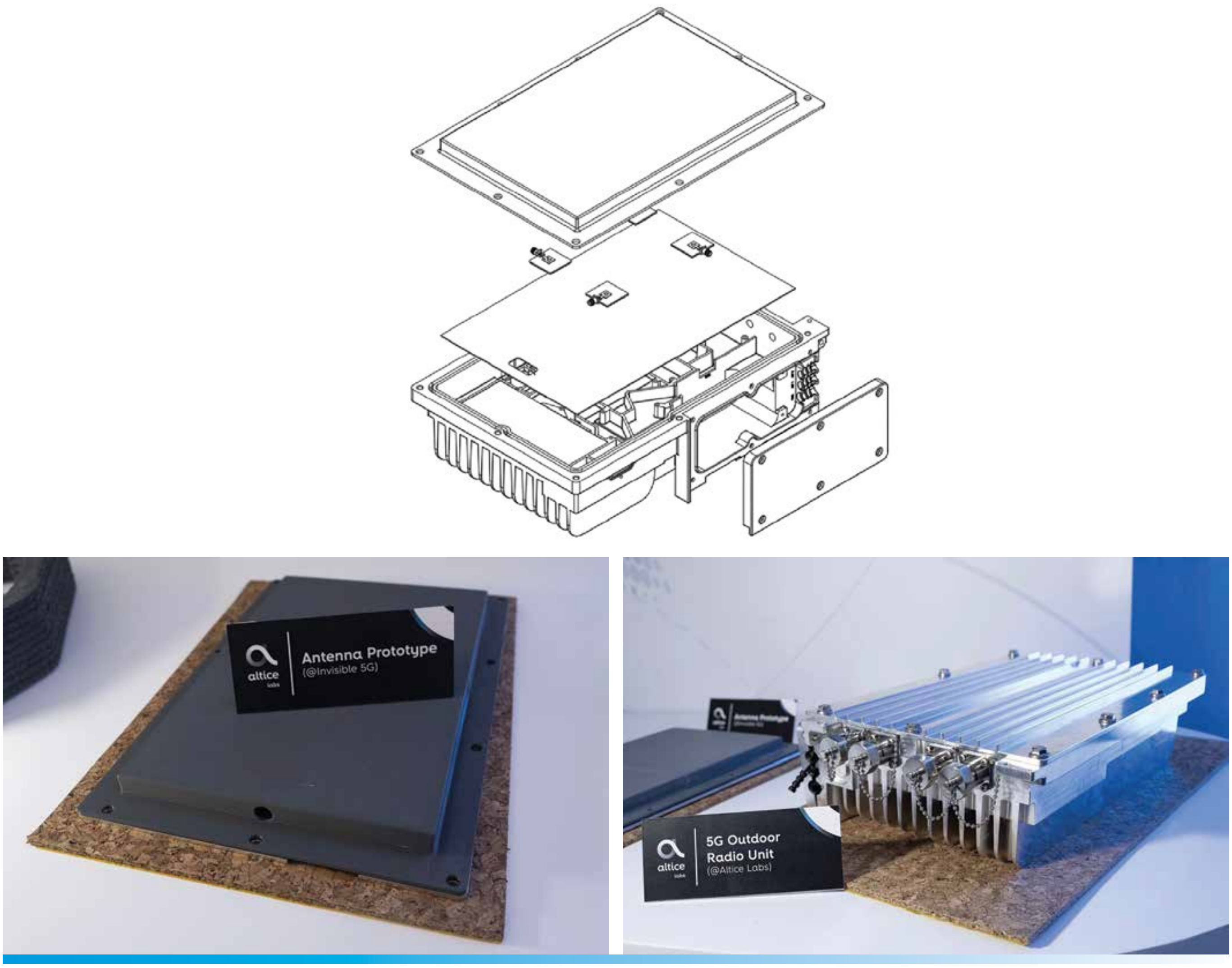

FIGURE 1 – Standard casing solution with embedded antennas

B - The Small informative casing

The second model developed was a Small informative casing (**Figure 2**) that hides the RU and the antenna through a camouflage strategy based on an informative function, which can be used either as an identification, directional or regulatory sign. A functional diagram of this mode is depicted in **Figure 2**.

The relatively small area of the informational support that hides the RU has a diameter of 50 cm, which brings it close to the scale of a traffic sign and allows its use as a support for pictographic language. In this case, the unidirectional antenna attached to the radio unit can also be used or, as alternative, it can be detached from the RU and be positioned on the opposite side of the pole, which allows the use of both unidirectional and omni-directional antennas. The cabling is completely hidden, being carried to the RU from the inside of the pole and connecting to the antenna through the horizontal metal support that connects the two elements to the lamppost.

The customization parameters in this model are essentially the graphic or visual content that may be placed in the Small informative casing, which allows an easy and low-cost customization. This solution is intended for urban environments where concealment is considered pertinent, but where it is necessary to install a solution of moderate cost and easy customization.

FIGURE 2 – Prototype of the Small informative casing

C - The Informative panel

The third model developed (**Figure 3**) consists of an information panel for urban areas with more demanding integration, which allows total concealment of all the elements that make up the system (RU, antenna, and electrical and optical fiber cabling).

This system allows a completely reversible installation, without the need to drill holes in the lampposts, allowing for its installation in public streetlamps with historical value or integrated into urban regeneration processes where there is a greater consistency in the urban equipment installed. The proposed system is based on the use of a customizable information panel, both in terms of shape and content, and a RU protection box designed by scanning the base of the existing poles, produced in recycled composite material through additive manufacturing. This solution presents a higher production complexity and is justified in scenarios where invisibility is considered as particularly relevant, such as historical centers or monuments.

The integration and concealment of the system can be optimized through the customization of the information panel, which although it always has a higher edge at about 2.5 meters from the ground (for the safety and efficiency of the antenna) can be adjusted in its width, to be more suitable to the location, facilitating its placement in circulation areas, squares, or gardens. A snap-in system has been designed to allow easy exchange of the panel.

The safety of the technical components (RU, antenna, and cabling) must be ensured by their integration in the information support, with the antenna and respective RU connection cabling integrated into the information panel and the RU in the base, protected by an external box.

FIGURE 3 – Rendering of the Informative panel (left) and custom protective case (right)

The final demonstration

The project was showcased in two public demonstration events, as depicted in **Figure 4**.

FIGURE 4 – Public demonstrations of the "Invisible 5G" project: (a) 7th Anniversary Event at Altice Labs; (b) Public demonstration at the ESTG/IPL campus

The first event occurred at the Altice Labs facilities in Aveiro during their 7th Anniversary celebration. This event was characterized by a targeted demonstration of a 5G small cell seamlessly integrated into a lighting pole, complete with an information panel. These detailed mock-ups were complemented by a promotional video that effectively highlighted the innovative solutions and outcomes of the project, providing a comprehensive and visually engaging demonstration of the project's achievements.

The second event was held at the Politécnico de Leiria - Escola Superior de Tecnologia e Gestão – Campus 2, and will continue to be operational even after the project's completion. This ongoing deployment serves as a data collection and network metrics platform, offering opportunities for potential network optimization. Furthermore, the sustained deployment at the Politécnico de Leiria offers a valuable opportunity to engage the local industry in their digital transformation efforts. It empowers production plants by providing 5G connectivity, allowing them to conduct testing and experimentation before making substantial investments in their digital infrastructure. This dual role not only supports network optimization but also promotes the integration of 5G technology into local industries, fostering innovation and growth.

Altice Labs: from 5G densification to 6G

Altice Labs has taken an active role researching and developing products and solutions for 5G densification. The company's contributions and vision are pivotal to the ongoing transformation of wireless communication networks, and they are shaping the path toward 6G smart radio environments (**Figure 5**).

Densification, or the strategic placement of small cells and base stations in high-demand areas, is a critical aspect of ensuring robust and reliable 5G connectivity, especially in densely populated regions. Altice Labs' efforts in this arena are multifaceted:

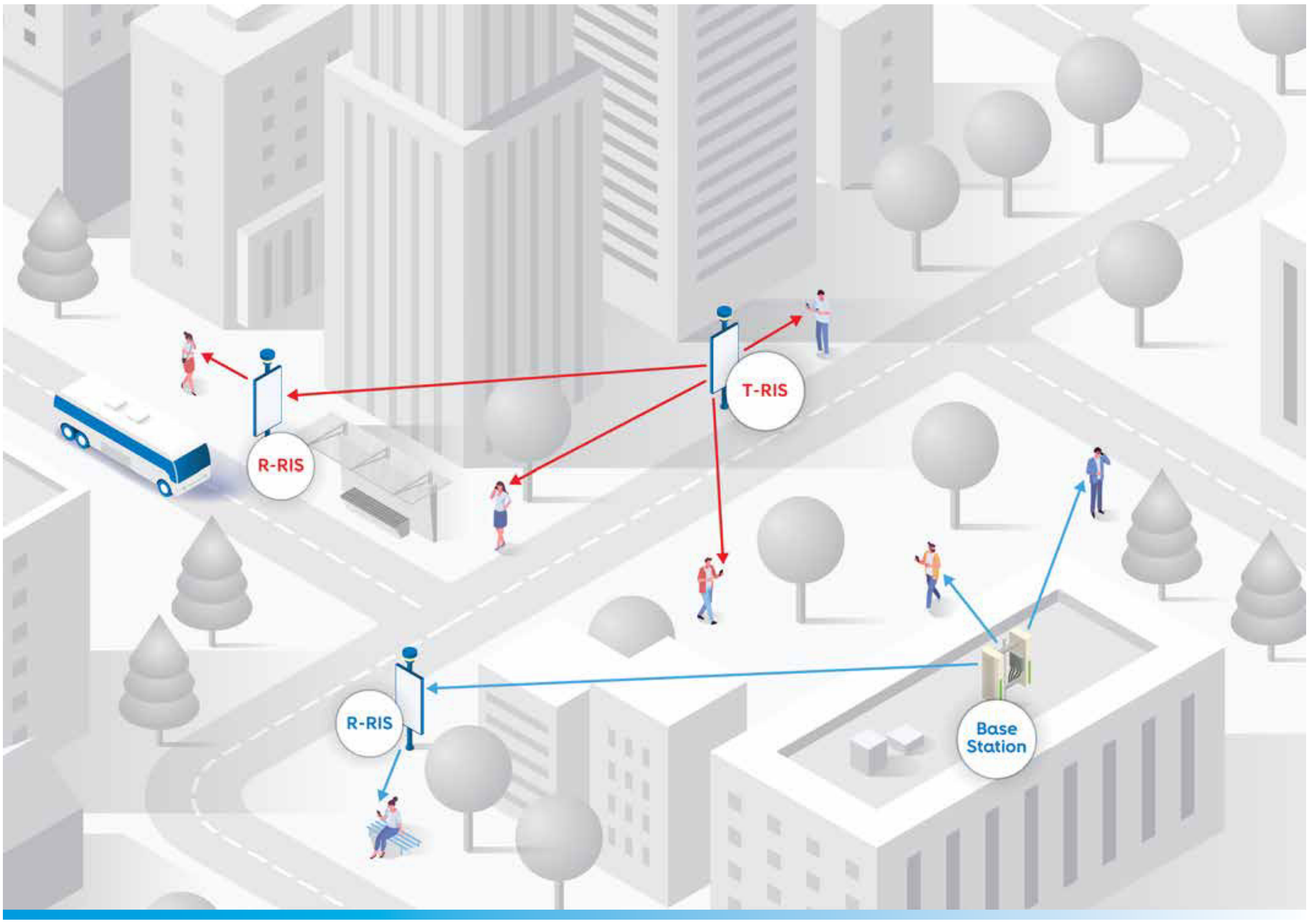

FIGURE 5 – Smart-radio environment scenario using T-RIS/R-RIS, for 6G and beyond

- **Technology innovation:** Altice Labs has invested significantly in research and development to create state-of-the-art, low-power, and highly concealed 5G small cells. These small cells are designed to seamlessly integrate with existing urban infrastructure, such as utility poles and lampposts, while delivering the performance required to meet the demands of 5G and beyond;
- **Urban integration:** the emphasis on integrating 5G infrastructure into the urban landscape sets a new standard for unobtrusive and aesthetically pleasing deployments. This approach not only addresses the technical challenges of densification but also ensures minimal visual impact on cities and communities;
- **6G preparedness:** the commitment to innovation extends to the future with a focus on 6G smart radio environments. By actively exploring the integration of reconfigurable intelligent surfaces (RIS), Altice Labs is laying the foundation for next-generation wireless networks that can deliver even higher throughputs and superior network quality.

The integration of RIS technology holds immense promise. RIS technology can dynamically manipulate electromagnetic waves, enabling advanced beamforming and interference management. This translates to substantially increased data rates and network performance, vital for future applications like augmented reality, holography, and immersive communication. Furthermore, in terms of energy efficiency, RIS can be used to optimize energy consumption, addressing one of the key challenges in wireless network deployments. The energy-efficient operation aligns with sustainability goals and contributes to reduced operational costs.

Evolving to 6G with Reconfigurable Intelligent Surfaces

The 5th generation of mobile network (5G) is being currently deployed worldwide. As natural evolution, the research community is now looking beyond 5G [1-3] and seeking for the next-generation of communications. Some authors [1-5] are already suggesting that 6G will go way further than the typical exploration of more spectrum at high-frequency bands, but it will rather be a convergence of upcoming technological trends driven by exciting, underlying services [5]. Some key enabling technologies for 6G are already being identified [1-3], with RIS being highlighted as a key technology for future wireless networks [3-5].

Within a radio channel and if deployed on a large scale, RIS structures would allow for the modification, on-the-fly, of the properties of the propagation channel (even though it remains physically unaltered). By doing so, it is possible to add, constructively or destructively, the propagating electromagnetic waves and suppress multi-path within the radio channel [10-12]. Like so, the radio channel will play, for the first time, an active role in wireless communications, and the performance of a communication system will not only depend on the intelligence of the transmitter and the receiver but also the intelligence of the radio path [10-12].

To date, plenty of examples of transmit and receive antenna arrays can be easily found in the literature [6-9]. However, most are typically demonstrated on a small scale, limited to antenna applications, with control performed locally. T-RIS and R-RIS, on the contrary, presuppose the use of a large-scale controlling mechanism that not only controls each local surface but optimally configures the most appropriate operation of several spatially distributed RIS, using artificial intelligence and machine learning algorithms to cope with real-time complex network planning [10-13].

Project TERRAMETA [14] joins key players in the design and development to investigate new technologies for 6G and demonstrate the feasibility of Terahertz in RIS for ultra-high-data-rate wireless communications networks. Novel high-performance hardware is being developed, and advanced network analysis/optimizations techniques will be developed.

T-RIS and R-RIS integration

Smart radio environments are revolutionizing the way we connect and communicate, and one of the most promising developments within this realm is the integration of T-RIS and R-RIS. These technologies promise to usher in a new era of wireless communication, ensuring seamless connectivity, improving coverage, and optimizing network efficiency.

Understanding T-RIS and R-RIS configurations

T-RIS (Transmitting - Reconfigurable Intelligent Surfaces): T-RIS is a critical component of smart radio environments. It comprises an array of reconfigurable intelligent surfaces that enable wireless devices to transmit signals more effectively. These surfaces consist of numerous small and controllable elements, which can adjust their properties to optimize signal transmission. T-RIS enhances communication by manipulating the phase and amplitude of transmitted signals, effectively steering them toward their intended targets, improving:

- **Micro coverage:** by customizing signal transmission, T-RIS allows for precise targeting of signals toward individual devices, including smartphones, IoT sensors, and other small, low-power devices. This enables micro-coverage users to enjoy enhanced connectivity and extended battery life;

- **Macro coverage:** T-RIS also improves macro coverage. By optimizing signal transmission, it can mitigate the effects of obstacles such as buildings, trees, and terrain irregularities. This results in more comprehensive network coverage and reduced dead zones, ultimately enhancing the user experience for a broader audience.

R-RIS (Reflecting – Reconfigurable Intelligent Surfaces): in contrast, R-RIS is designed to enhance the reflection of incoming signals. This technology uses reconfigurable intelligent surfaces that consist of specially designed materials or structures. R-RIS intelligently reflects incoming signals toward their intended destinations, playing a pivotal role in extending macro coverage in smart radio environments:

- **Reflection of signals:** R-RIS intelligently reflects incoming signals, effectively redirecting them toward their intended destinations. This technology is particularly valuable in urban areas with tall buildings and complex layouts, where signals may be blocked or weakened due to obstacles;
- **Eliminating dead zones:** by strategically reflecting signals, R-RIS can fill in coverage gaps, eliminating dead zones within a network. This ensures a more consistent user experience, especially for macro users who may be on the move;
- **Improved penetration:** R-RIS is also capable of improving signal penetration through buildings and structures. This is a critical benefit in scenarios where users need connectivity in indoor environments, such as shopping malls, airports, and office buildings;
- **Reducing interference:** R-RIS not only extends coverage but also helps reduce interference caused by multipath signals and signal reflections. This results in a cleaner and more stable connection;
- **Network load balancing:** R-RIS can be dynamically configured to balance network load by selectively reflecting signals to alleviate congestion in high-traffic areas, thereby improving the overall network's performance.

In summary, this innovation brings us closer to achieving the goal of ubiquitous and reliable wireless communication in diverse settings. Due to their typical planar architecture and associated low power consumptions, such devices can be easily adapted, e.g., to the informative panel developed in the "Invisible 5G" project, as illustrated in **Figure 6**.

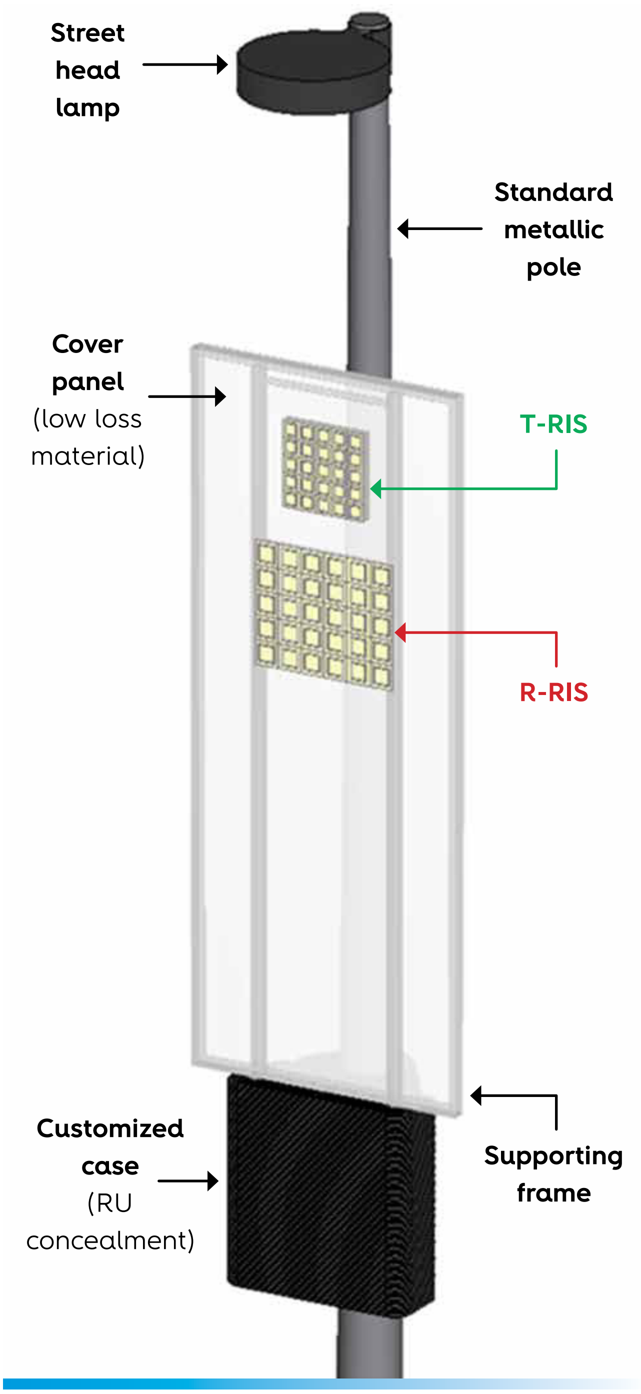

FIGURE 6 – Informative panel of project "Invisible 5G" with T-RIS and R-RIS solutions

Conclusions and future prospects

In conclusion, the concept of densification emerges as a pivotal driver for the successful implementation of 5G and the anticipated arrival of 6G networks. Our work, focused on the specific challenges presented by the need for small-cell deployment in urban environments, signifies a fundamental shift in the evolution of mobile communications technologies in Portugal and beyond.

The drive towards densification is essential for bringing 5G and the future 6G closer to end-users, offering unprecedented opportunities for technological advancements in communities and infrastructures. The proposal for state-of-the-art, invisible 5G small cells was poised to revolutionize traditional base station deployment, promising low-power, small-form-factor, ruggedized, and highly concealed solutions that seamlessly integrate with urban furniture.

Altice Labs' research and development work in the 5G densification race and the introduction of reconfigurable intelligent surfaces (RIS) represent a significant leap forward. This ground-breaking solution not only advances the mobile communications sector but also offers export potential, positioning Portugal as a product supplier on a global scale.

The journey from 5G densification to 6G smart radio environments, coupled with the innovative RIS integration, propels the mobile broadband arena into a new era. This visionary approach promises to redefine connectivity in urban landscapes, underlining its significance in the continuous evolution of wireless communication technologies.

Through collaborative partnerships with academic institutions and research laboratories, the journey toward densification and the evolution of invisible 5G small cells has been enriched by cutting-edge research and continuous learning and adaptation. Central to these pioneering advancements in 5G densification, 6G smart radio environments, and the integration of reconfigurable intelligent surfaces has been a steadfast commitment to collaboration with academia and research labs. This visionary approach recognizes the invaluable contribution of knowledge sharing and cross-disciplinary efforts to drive innovation in the realm of telecommunications.

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