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6G Positioning and Sensing Through the Lens of Sustainability, Inclusiveness, and Trustworthiness

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***Abstract*—6G promises a paradigm shift by integrating positioning and sensing, enhancing not only the communication performance but also enabling location- and context-aware services. Historically, positioning and sensing were focused on cost and performance tradeoffs, implying an escalated demand for resources, such as radio, physical, and computational resources, for improved performance. However, 6G expands this perspective, embracing a set of broader values, namely sustainability, inclusiveness, and trustworthiness. From a joint industrial/academic perspective, this paper aims to shed light on these important value indicators and their relationship with the conventional key performance indicators in the context of positioning and sensing.**

I. Introduction and Motivation

Integrated sensing and communication (ISAC) is expected to be a major differentiator of 6G when compared to previous generations [1]. The promises of ISAC include pervasive situational awareness by *radar-like sensing* (detection and tracking of objects) and *non-radar-like sensing* (e.g., weather, material, and spectrum sensing), complemented with extremely accurate *position and orientation estimation of devices*. These promises are expected to materialize thanks to a variety of technological advances, including use of the mmWave and sub-THz spectrum, reconfigurable intelligent surfaces (RISs), artificial intelligence (AI), novel radio frequency (RF) hardware, etc. In turn, ISAC will enable new applications with unprecedented demands in terms of the key performance indicators (KPIs) (e.g., accuracy, latency, coverage), such as extended reality, digital twinning, and collaborative robotics [2].

The timing of 6G is well-aligned with the Agenda 2030 for Sustainable Development by the United Nations (UN). Under this agenda, 17 interlinked sustainable development goals (SDGs) have been defined, which serve as a "shared blueprint for peace and prosperity for people and the planet, now and into the future" [3]. The European Hexa-X 6G Flagship project, which includes representatives of all stakeholders involved in the 6G value chain, ranging from vendors, operators, IT industry, and high-tech companies, has established that 6G can contribute to certain SDGs [4], through a holistic approach towards societal, economic, and environmental sustainability. Hexa-X also interacted with other major 6G fora, such as the International Telecommunication Union (ITU), which in its definition of 6G (called IMT-2030), defined four overarching aspects (sustainability, ubiquitous intelligence, security/privacy/resilience, and connecting the unconnected) that act as essential design principles applicable to all usage scenarios.

To extend the view of the conventional KPIs towards a more comprehensive value-driven approach, key value indicators (KVIs) have been introduced in [4] to complement the KPIs and are able to better capture the spirit of the SDGs. The KVIs have been defined in three categories: *sustainability*, *inclusiveness*, and *trustworthiness*. Hence, the 6G system should itself meet each of these KVIs, not only during the lifecycle of its components, but also by enabling services and applications that can, in turn, improve the KVIs. This KVI-inclusive vision of 6G positioning and sensing is depicted in Fig. 1, and will be elaborated in the following sections.

In this paper, based on inputs from stakeholders across the value chain, including telecom vendors, large and small industry, and academia, we aim to describe and structure the KVIs for 6G in the context of ISAC (i.e., communication, positioning, and sensing), reveal their synergies and conflicts, and propose a methodology to quantify them (thus effectively turning them into new KPIs). As positioning and especially sensing has more diverse KPIs than communication in different scenarios, there are many ways to connect conventional KPIs and new KVI-induced KPIs, providing additional opportunities (e.g., possibility to optimize KVIs) as well as challenges (e.g., more constraints to handle) to optimize 6G systems. Each KVI will also be discussed in detail, shedding light on the dual role of 6G. By integrating these KVIs into the architectural design of 6G ISAC, we anticipate not only novel research avenues but also the facilitation of achieving the SDGs. While this paper focuses on the technical aspects related to the 6G KVIs, they can also be supported by policy mechanisms at international, regional, and national levels.

II. Performance and Value Indicators

In this section, we elaborate on the 6G use cases and the corresponding KPIs. Then, we detail the three KVIs and their relation to the KPIs.

A. 6G Use Cases and KPIs

The typical 6G use cases can be clustered according to several verticals: healthcare, automotive, industry, and extended reality. Positioning and sensing information can also be used internally by the 6G system to enhance and optimize communication functionality, for example using position information to optimize proactive resource allocation. According to the use

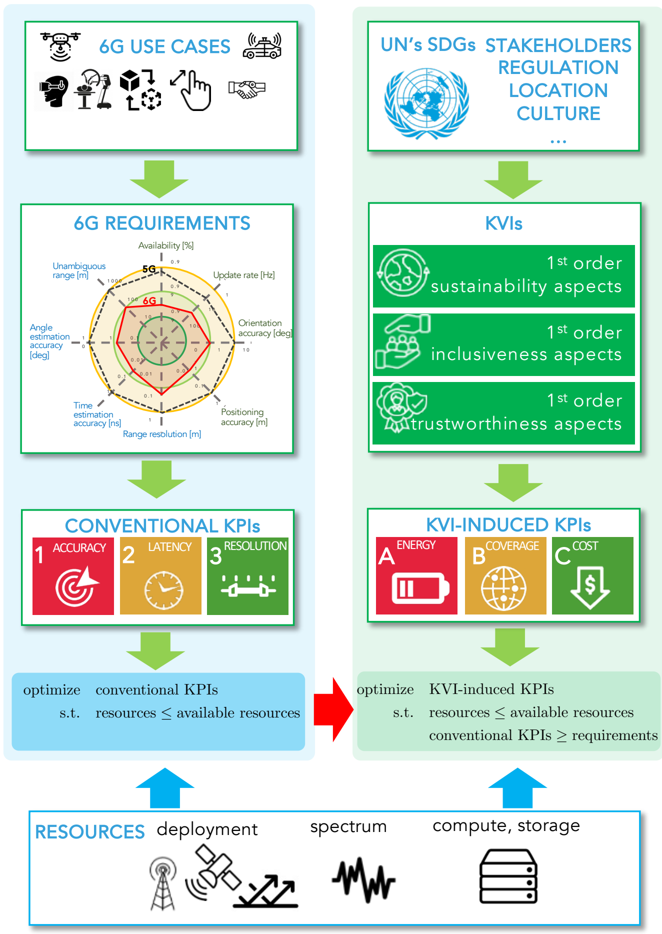

Fig. 1: A methodology for accounting for KVIs in 6G design. The conventional design optimizes the conventional KPIs with respect to the resources, while we propose a broader approach, where first-order KVIs are transformed to KPIs and these KVI-induced KPIs are optimized instead.

cases, the corresponding positioning requirements are expected to be tighter than the ones for the existing 5G standard [2], as depicted in the left part of Fig. 1. Moreover, new sensing requirements must be introduced in alignment with the specific use cases. Definition of positioning and sensing requirements in 6G is done through the lens of KPIs, which are a function of the underlying radio resources and algorithms. Examples of positioning and sensing KPIs include accuracy and resolution, latency, availability, classification accuracy, detection probability, and update rate. A comprehensive exploration of the use cases and KPIs is beyond the scope of this paper, but is available in [2].

B. The 6G KVIs Explained

The inception of value-based considerations in 6G, though initially introduced in [4], has philosophical roots that can be traced to broader social awareness and responsibility [5]. The concept of *value*, as delineated by [4], encompasses "intangible yet essential human and societal imperatives, including growth, sustainability, trustworthiness, and inclusion." The operationalization of these values within the 6G framework necessitates the formulation and integration of associated criteria, in the design, functionality, and decommissioning of the system. While [4] refrained from explicit definitions of these values and the KVIs, we regard them as analogous. Our objective is to provide useful definitions for each KVI that are comprehensive yet specific, a task that will be further expounded in the context of 6G positioning and sensing in the next section.

Sustainability bifurcates into environmental and economic domains.[1] Economic sustainability pertains to practices that support long-term economic growth, balancing organizational and societal needs without undermining social, environmental, and cultural facets. Environmental sustainability was already highlighted in the 4G era [6], where life cycle analyses indicate that a holistic approach must incorporate considerations of manufacturing, operational energy consumption, recycling practices, and end-of-life treatment. However, with 6G these considerations must be considered already in the design and standardization phase.

Inclusiveness is multifaceted and aims to foster increased participation and mitigate digital divides, promoting an equitable technological landscape. Inclusiveness encompasses accessibility to 6G technologies, education, and facilitation in their usage, as well as assisting vulnerable demographics, such as the elderly or infants, and those marginalized due to geography, gender, culture, health, education, or other reasons.

Trustworthiness encompasses security (defense against deliberate attacks), robustness (mitigation of unintentional faults, including environmental disturbances, human errors, and system malfunctions), and privacy (unauthorized leakage of sensitive information, whether deliberate or inadvertent) [7]. Notably, the anticipated pervasive utilization of AI in 6G introduces unprecedented challenges and considerations in the realm of trustworthiness, necessitating innovative approaches.

C. Relations Between KPIs and KVIs

An intricate relationship exists between the conventional KPIs and KVIs, underlined by a multifaceted interplay of trade-offs and synergies, as visually depicted in Fig. 2. This relationship is further elaborated below, incorporating the quantitative methodologies for KVIs and exposing the challenges emanating from potential knock-on effects.

1) Trade-off between KPIs and KVIs: Achieving a particular KPI might necessitate a compromise on a corresponding KVI. Pursuing heightened accuracy might demand extensive infrastructure deployment or resource consumption, undermining sustainability. Consequential impacts may manifest in reduced trustworthiness (owing to a less diversified technology ecosystem) and diminished inclusiveness (resulting from unaffordable services for specific demographics). Conversely, elevating a KVI may cause conflicts with KPIs. The construction of a trustworthy system, albeit fostering secure services and long-term reliability, might entail additional resources or complex algorithms. This, in turn, might introduce latencies or degrade performance within the given resource constraints, affecting the associated KPIs. Enhancement in one KVI may

[1]Given that all SDGs are by definition related to sustainability, a more narrow definition is proposed.

result in unintended repercussions in another KVI. For instance, to improve inclusiveness, we need to improve the sensing coverage. However, improving the sensing coverage in places where there are privacy concerns might harm the trustworthiness (and the acceptance of the technology).

2) Synergy between KPIs and KVIs: Certain scenarios reveal mutual support between KPIs and KVIs. Accurate position and map information can improve energy efficiency via so-called channel knowledge maps. Enhancements in positioning and sensing, coupled with broadened service reach, can promote user inclusiveness. This may, in turn, catalyze commercialization and privacy through distributed processing, thereby enabling accurate cooperative positioning. Trustworthiness and sustainability are valued intrinsically by users, thereby amplifying inclusiveness through wider adoption. By carefully exploiting these synergies, future networks can be designed to concurrently optimize both KPIs and KVIs, ensuring both performance objectives and broader societal benefits are achieved. A salient instance of this synergy manifests in hardware impairment exploitation, where attributes of cost-efficient hardware (contributing to sustainability and inclusiveness) can be harnessed to enhance KPIs, such as sensing accuracy and unambiguous range [8].

3) Quantification of KVIs: While KPIs can offer quantifiable metrics for evaluating positioning and sensing performance in 6G networks, quantifying KVIs poses a formidable challenge as they often encompass essential societal values that lack a rigorous mapping to tangible metrics [4]. To address this challenge, a possible methodology is visualized in Fig. 1, where the conventional principle of optimizing KPIs subject to resource constraints, is replaced with KVI-driven approach. Given the use case and the context (including SDGs, culture, and regulations), the first-order KVI aspects can be identified. These first-order aspects are then mapped into so-called *KVI-induced KPIs*:

- **Sustainability-induced KPIs:** Relevant KPIs include *energy efficiency*, which is relatively well-defined for communication, but not for positioning and sensing, as well as capital expenses (CAPEX) (e.g., deployment cost) and operational expenses (OPEX) (e.g., power consumption of components or systems).
- **Inclusiveness-induced KPIs:** Possible KPIs include *coverage* that can be provided within the legacy KPI (e.g., accuracy and latency) requirements, *cost* of the device or service for the end-user, *accuracy* of new human-machine interfaces (e.g., via gesture recognition).
- **Trustworthiness-induced KPIs:** The broad nature of trustworthiness requires metrics like *position integrity* to ensure robustness against faults, and security evaluation through the *probability of undetected or wrongly detected attacks and the subsequent impact*. Privacy considerations may invoke measures such as *differential privacy* and *mutual information* metrics.

This approach then naturally allows for optimization of the KVI-induced KPIs, which can be optimized, still meeting the KPI requirements, as again depicted in Fig. 1. While this methodology cannot fully capture the high-order effects (e.g., improved coverage may cause people to travel further and use more fossil fuels, thus reducing sustainability), it offers a first attempt for a value-oriented 6G design.

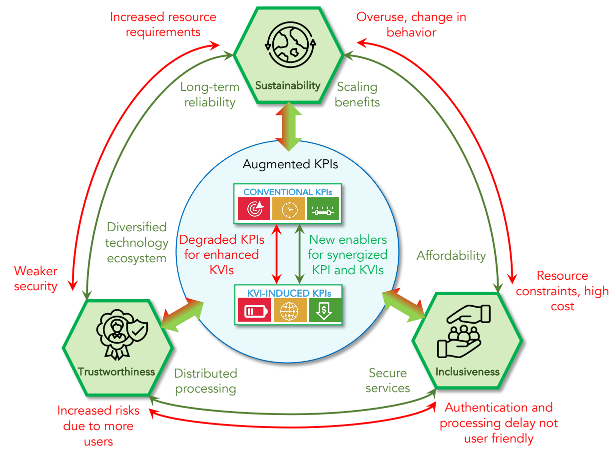

Fig. 2: Synergies (green) and trade-offs (red) among KPIs and KVIs, including higher-order effects. KPIs must be extended to quantify the KVIs in 6G design, when possible.

D. A Quantitative Analysis Example

Fig. 3 applies the methodology from Fig. 1 and considers a quantitative analysis of a communication KPI (namely rate in Gb/s with respect to the closest base station (BS), computed via the Shannon–Hartley Theorem) and positioning KPIs (namely (i) a bound on the positioning root-mean-squared-error (RMSE) based on all BSs, computed via a Fisher information analysis, and (ii) the protection level, defined as the 90% confidence interval in 2D, also derived from Fisher information analysis), as a function of the number of BSs, considering a 5.9 GHz carrier, 80 MHz bandwidth, 0.1 W transmit power per BS for pilot transmissions of 25 us per BS, and line-of-sight (LoS) channels.[2] Users are uniformly deployed in a 4 km^2 area and BSs according to a regular grid within this area. The design should be inclusive (captured by the KPIs that can be attained for 95% of the users, or, equivalently the deployment area), sustainable (captured by the CAPEX (number of BSs) and OPEX (the power consumption per active BS), and trustworthy (captured by the protection level). These together comprise the KVI-induced KPIs. Many insights can be drawn from this figure.

1) **KPIs have first-order impact on KVIs:** The conventional KPIs (rate and positioning accuracy), which all benefit from more BSs and more transmission power, will make the design less sustainable (CAPEX and OPEX).
2) **KVIs can be in trade-off:** Sustainability and inclusiveness are in contrast, so for a solution to be more sustainable it will be less inclusive and vice versa since a more inclusive design requires more resources. For instance, a non-inclusive design (which serves 50% of users, with a target positioning RMSE) is much less costly from a sustainability perspective than a design that is inclusive and reaches 95% of the users (with the same target positioning RMSE).

[2] Source code at https://github.com/henkwymeersch/6GpositioningKVIs.

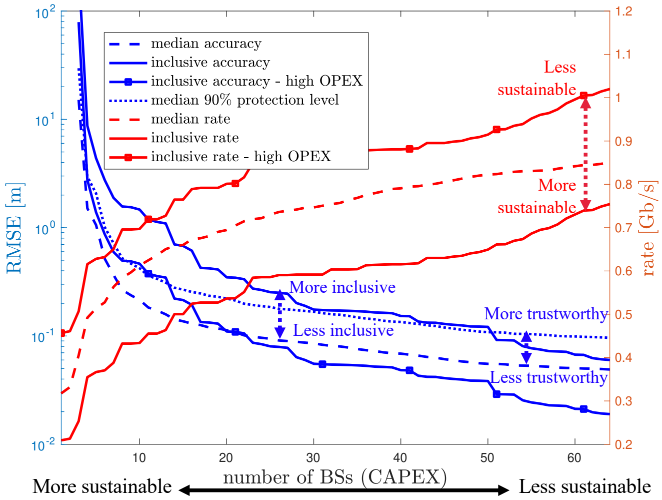

Fig. 3: Quantitative analysis of KVIs with mapping to KPIs. Conventional KPIs (positioning accuracy and communication rate), vs. number of BSs (representing the CAPEX). Sustainability is measured through the number of BSs and the total power consumption. Inclusiveness is measured through the 95% (across users or locations) attainable KPI values. Increasing the power consumption (OPEX) 10× improves the inclusive KPIs. Trustworthiness is measured through the protection level.

3) **Non-linear relations between KVIs:** Small reductions in conventional KPIs can lead to large savings in KVIs. For instance, reducing the target RMSE from 0.1 m to 0.3 m, allows a 10× reduction of BS transmit power.
4) **Not all KPIs are equally important for KVIs:** The positioning KPIs have a much wider variation than the communication KPI, meaning that (i) positioning and sensing will likely be bottlenecks for both sustainability and inclusiveness, but also (ii) we can gain in terms of the KVIs by relaxing selected KPIs (e.g., by allowing sensor fusion), as shown in the blue curves with a few numbers of BSs.

III. The Dual Role of Positioning and Sensing from a KVI Perspective

In this section, we go deeper into each of the KVIs, to provide specific examples of how they relate to positioning and sensing in 6G. For each KVI, a dual view is taken. First of all, we consider how the network can operate in a way that makes positioning and sensing aligned with each value, with the help of the key 6G technologies [2] (including RIS, non-terrestrial network (NTN), sidelink, AI, distributed multiple-input multiple-output (D-MIMO), and sub-THz signals). Conversely, we consider how 6G positioning and sensing, conceptualized as a service, can improve the KVIs of applications and scenarios in verticals.

A. Sustainability

Sustainability is arguably among the major concerns in 6G systems, guiding the entire lifecycle design.

1) Sustainable Positioning and Sensing: We consider three dimensions of sustainable design: radio resource optimization, infrastructure optimization, and the level of integration of positioning and sensing within 6G communication.

- *Radio resources:* Positioning and sensing require radio resources for their operation, which consume transmit power. Conservative designs based on over-provisioning should be avoided in favor of flexible and adaptive resource allocation schemes, such that energy and resource consumption can be minimized, while still (exactly) meeting the instantaneous target KPIs. Complementary to the radio resources, sleep/idle modes should be activated whenever possible to conserve energy.
- *Infrastructure:* Positioning and sensing generally require a more extensive infrastructure deployment than communication. Such an extension is provided in 6G through two emerging technologies: D-MIMO systems and RISs. In D-MIMO deployments, user equipments (UEs) are surrounded by a large number of energy-efficient BSs, providing not only outstanding performance in communication but also in positioning and sensing. RISs are a class of low-energy equipment that can replace/complement location anchors (e.g., BSs) and manipulate the wireless environment [9], resulting in better propagation channels, especially in the presence of blockages. Similar to the radio resources, the infrastructure should be optimized, for instance, the deployment, the manufacturing, and the replacement possibility of D-MIMO and RIS systems, to improve sustainability under long-term target KPI requirements.
- *Level of integration:* One of the key features of 6G is to use resources and infrastructures for both positioning/sensing and communications, thereby inherently improving sustainability. The integration of positioning/sensing and communications can span different levels, from sites, spectrum, and infrastructure, to waveforms and time/frequency resources. While progressive integration improves sustainability, there are unavoidable trade-offs in terms of performance. Hence, stringent KPI requirements may not be suitable for the tightest possible integration.

2) Positioning and Sensing for Sustainability: Positioning and sensing, through their ability to understand and digitize the physical world, provide a unique tool to enhance sustainability. First of all, by harnessing positioning and sensing information, data communication sustainability can be improved (e.g., context-aided communication with proactive resource allocation, beam alignment, and blockage avoidance) [10]. In addition to the more sustainable operation of communication, the ability to sense and localize has broader sustainability implications, such as earth monitoring (e.g., the ability to monitor pollution and weather), relying on non-radar-like sensing modalities. Recalling the verticals from Fig. 1, sustainability benefits in healthcare include the reduction in CO2 emissions thanks to remote surgery and drone deliveries, when compared to traditional means of transporting people and goods via planes and ground vehicles. In the automotive sector, traffic coordination and platooning supported by 6G sensing can be used to minimize fuel/battery consumption. In the industry vertical, digital twins (e.g., twins for manufacturing and autonomous supply chains, twins for sustainable food production, or twins in the context of immersive smart cities) can track the position of assets or humans via 6G to optimize processes, save material, and reduce waste or energy per produced item. Finally, in the realm of extended reality, the ability to collaborate virtually can lead to enormous CO2 savings, due to reduced ground and air travel.

B. Inclusiveness

In the pursuit of global digital equity, 6G should ensure accessibility to all humans, irrespective of gender, age, ability, and geographical location [11]. An integral part of this vision is to make the technology affordable, scalable, and ubiquitous. As such, positioning and sensing are the core aspects of this inclusive objective.

1) Inclusive Positioning and Sensing: Positioning and sensing, embedded in the network architecture, can be facilitated by network deployment across all geographical terrains. This is feasible through a combination of several developments: the reuse of communication resources and infrastructure for multi-purpose functionality, ubiquitous connectivity, and cooperative networks.

- *Multi-purpose functionality:* The infrastructure for providing communication and network services will be repurposed for positioning and sensing functions. A proof-of-concept for this dual-purpose application is illustrated in Fig. 4, where communication signals are used to track a person.
- *Ubiquitous connectivity*: The incorporation of NTNs will significantly extend the coverage of 6G networks to remote or difficult-to-reach areas, ensuring that geographical barriers do not limit access to vital communication or sensing services. Similarly, RISs also enhance and enable accurate and efficient positioning and sensing in various scenarios, largely extending the coverage of services [12]. Consequently, ubiquitous connectivity-enabled positioning is poised to significantly augment the inclusiveness of the 6G network by enabling uninterrupted connectivity regardless of the users' proximity to the traditional network infrastructure.
- *Cooperative networks*: Sidelink supports direct communication between devices, bypassing the centralized network infrastructure. This capability can facilitate the creation of localized communication networks, extending connectivity and service availability in scenarios where conventional network coverage may be absent or limited, such as in rural, remote, or disaster-struck areas. Such a cooperative approach makes positioning and sensing tasks to be completed in a distributed manner, largely extending the coverage and reducing the cost of the provided services.

These three aspects underscore how 6G technology will be instrumental in breaking down existing barriers in network access and functionality, demonstrating a firm commitment to creating a truly inclusive, global digital ecosystem.

2) Positioning and Sensing for Inclusiveness: Inclusiveness in 6G networks is not only a macro-level objective but also addresses the accessibility challenges encountered at the micro-level of individual human-machine interactions. Positioning and sensing can play a crucial role in this context. On the one hand, advancements in sensing technology will enable systems that can interpret and respond to gestures, which benefits individuals who face challenges in traditional interaction modalities. Such a transformation can redefine the nature of human-machine interaction, making it more inclusive and accessible. On the other hand, intelligent monitoring, especially in critical societal domains such as elderly care, patient supervision, and infant care, emerges as a domain where sensing can be a game-changer, by advanced gesture or posture classification or breathing monitoring based on micro-Doppler. Such integrative applications promise to redefine caregiving, providing options characterized by precision, real-time feedback, and remote monitoring. These developments serve to enhance the quality of life for these demographic segments, underlining 6G's commitment to be genuinely inclusive and beneficial to all of society. Referring back to the proof-of-concept demonstration from Fig. 4, a person can be tracked in a cluttered environment with the aid of 6G communication signals and infrastructure, negating the need for additional equipment or invasive monitoring.

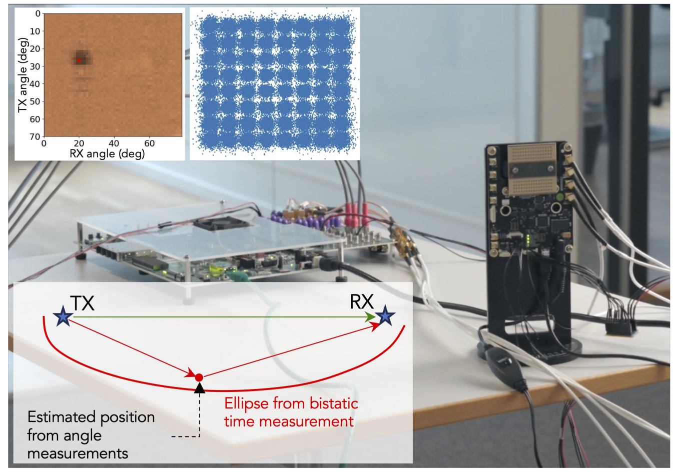

Fig. 4: Proof-of-concept for joint communication and sensing, showing how existing communication infrastructure and signals can be repurposed for sensing, in support of sustainability and inclusiveness. The hardware comprises Sivers semiconductors EVK06002 as transmitter (TX) and receiver (RX), each with 1×16 arrays. Standard 5G waveform with 120 kHz subcarrier spacing, 800 MHz bandwidth, 69 GHz carrier frequency, and 64 QAM modulation are employed, yielding a maximum rate of 560 Mb/s. Besides the data transmission (top middle), beam sweeping (top left) provides bearing measurement of the passive target. Bistatic time measurements provide a sensing ellipse to further improve the target position estimate (bottom left). The sensing resolution is 40 cm and the sensing duration is 6.25 ms (2800 beam combinations and 2 OFDM symbols per beam pair) [13].

C. Trustworthiness

Ensuring the robustness, security, and privacy of 6G positioning and sensing must be a priority in the design of the overall 6G system, given the safety-critical nature of the verticals. This section outlines challenges and approaches related to the trustworthiness of positioning and sensing in 6G.

1) Trustworthy Positioning and Sensing: We deconstruct trustworthiness into its constituent elements, such as robustness, security, and privacy, before discussing the influence of, e.g., AI, on them separately.

- *Robustness:* Robust positioning and sensing are primarily based on diversity, relying on a large set of measurements from independent technologies, observations, or dimensions, to provide redundancy for detecting and eliminating faults. This approach is common in global navigation satellite system (GNSS), where for instance, aviation applications demand protection levels with a high degree of certainty, even in the presence of faults. The 6G system itself can provide inherent redundancy, via diverse measurements (e.g., not only time-difference-of-arrival (TDoA), but also angle-of-arrival (AoA), angle-of-departure (AoD), carrier phase, and perhaps Doppler), diverse location references (e.g., using many access points in D-MIMO), and multi-sensor fusion (e.g., relying on a combination of 6G sensing with vision). When combined with integrity monitoring, 6G can provide high performance with guaranteed robustness [14].
- *Security:* Vulnerabilities exist in classical positioning technologies (e.g., GNSS and ultra-wide band (UWB)), where attackers can perform jamming (blinding the receiver, leading to service interruption), meaconing (retransmission of legitimate signals), or spoofing (transmission of false signals) [15]. Spoofing can be mitigated by cryptographic countermeasures, while jamming can be mitigated by directional nulling at the receiver. Attacks on radar sensing include jamming, altering electromagnetic properties, deception, masking, and imitation. Adaptive waveform design and frequency hopping help correct target range or velocity errors. Extrapolating these concepts to 6G, it is clear that each measurement type (delay, angle, Doppler), each piece of hardware (BS, RIS, UE), and each waveform have potential security weaknesses that can compromise positioning and sensing. An example of a positioning and sensing attack in a 6G context is shown in Fig. 5, where an attacker manipulates the TX beamforming, which leads to perceived high-power paths at the RX with modified AoD (with limited knowledge at the attacker) or AoA (with complete knowledge at the attacker).
- *Privacy:* Privacy protection in the area of location tracking of humans is already crucial for 5G and comes even more into focus with 6G's higher positioning accuracy (including its opportunities for cross-platform fusion of tracking information, and exposure framework for internal and external use). Position information that can be easily used for behavioral profiling must be secured from unauthorized access on all levels (including physical-layer security). Moreover, not only tracking of humans is possible but tracking of objects and assets as well. In corporate environments, where asset tracking is used to monitor and optimize processes, this process information becomes worthwhile protecting as well. Technological protection includes solutions such as active cloaking, reminiscent of techniques in electronic warfare.

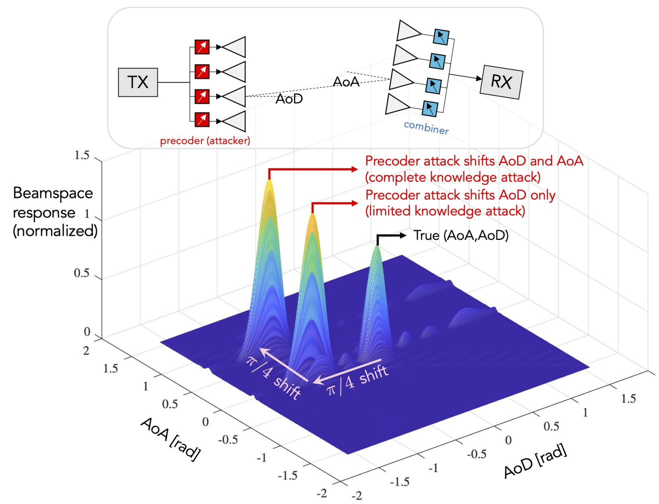

Fig. 5: A 6G ISAC attack example, where a transmitter modifies its beamforming vector to fool an analog/hybrid receiver, each with 16 elements into believing there are additional (strong) paths at controlled AoD or AoA, shifted $\pi/4$ in each domain with respect to the LoS path at AoD and AoA of 0 radians.

In the context of the trustworthiness of 6G, the advent of AI has the potential to instigate novel attacks, exploiting latent system vulnerabilities. Conversely, AI can fortify system security and privacy by innovating newly learned protocols or waveforms. However, the opaque nature of AI mechanisms demands rigorous and transparent scrutiny, especially for safety and mission-critical tasks. Formal verification methods such as model checking which are commonly employed in hardware system design can be used to verify complex AI models. Some of the properties that these models verifies could provide necessary explanations for these tasks.

2) Positioning and Sensing for Trustworthiness: The ability to localize users and objects with a high degree of accuracy can support applications that rely on trustworthiness. First of all, in terms of robustness, 6G network/system will act as an additional sensor, complementing and verifying existing sensors (e.g., camera, GPS, lidar, radar, inertial measurement unit). This will benefit all safety-critical services (including the corresponding communication), where incorrect location information may lead to harm. Secondly, security functions can be based on accurate location information or biometric 6G sensing data can be employed in access control or payment services. Given the built-in encryption and security frameworks, 6G data is poised to receive greater trust than other sensory inputs, driving the emergence of novel applications. Lastly, surveillance and crowd control applications are envisioned to benefit immensely from the sensory data facilitated by 6G.

D. Impact of 6G Enablers on the KVIs

To conclude this section, we offer an overview of several key technological enablers for 6G positioning and sensing, [2] (namely, RIS, NTN, sidelink, AI, D-MIMO, and sub-THz signals) and list *exemplifying benefits and drawbacks* in terms of the KVIs (see Table I), based on analyses conducted in Hexa-X [13]. The precise trade-offs and synergies and

Enablers↓	Pro Sustainability	Con Sustainability	Pro Inclusiveness	Con Inclusiveness	Pro Trustworthiness	Con Trustworthiness
RIS	low energy consumption for P&S compared to BS	additional RIS deployment costs	low cost compared to additional BSs and extended coverage	focused radio wave exposure concerns; limited coverage extension compared to BSs	RIS links provide redundancy, increasing P&S robustness and integrity	The RIS itself attacks the network, leading to spoofed P&S measurements
AI	can learn to optimize CAPEX and OPEX for P&S	training and inference complexity leads to high energy consumption	can support P&S functions to serve non-connected users, e.g., remote monitoring	expensive infrastructure could limit accessibility to certain regions or groups	AI can be used to detect anomalies in P&S measurements or received signals	AI decisions are not always explainable; AI can be used to learn new attacks
NTN	1 satellite or high altitude platform station can replace several base stations in P&S	additional deployment costs and difficult to decommission	extreme P&S coverage enhancements in under-served regions	possibly high service fees; scarce spectrum limits sensing resolution	very difficult to tamper with NTN P&S signals	NTN signals are easier to jam due to their lower power
D-MIMO	short distance to user leads to reduced power consumption and more geometric diversity	high density deployment and additional cabling required	uniform P&S coverage and flexible architecture	mainly for dense areas with many users and good fiber network	high level of redundancy due to many possible links, increasing robustness and integrity of P&S	possibility for pervasive and continuous tracking of users leads to privacy concerns.
Sub-THz	extreme focusing provides high SNR links; can replace cabled solutions	low efficiency of power amplifiers and limited use cases	new sensing services (e.g., imaging) at low cost with needed dedicated equipment	mainly for nearly static links	directional links avoid eavesdropping and limit impact of jamming	limited robustness due to links drop under mobility or environmental effects
Sidelink	provides connectivity for sensing with fewer BSs	extensive coordination signaling needed; draining user device batteries more quickly	can provide P&S services with limited or no infrastructure deployment	limited to relative P&S and sensing without infrastructure	local communication and coordination of P&S does not leak into the network	lack of central unit limits security mechanisms

TABLE I: Selected enablers for 6G positioning and sensing (P&S) and example benefits (Pro) and drawbacks (Con) in terms of the impact on the KVIs, based on analysis in the Hexa-X project [13].

associated benefits and drawbacks depend on the specific use case and its requirement, so the entries in Table. I should be interpreted as examples, not guidelines or general conclusions. It is also important to note that several of the benefits and drawbacks emanate from higher-order effects, underscoring the intricate and multifaceted nature of 6G system design.

IV. Outlook

The evolution of precise positioning and sensing for 6G ISAC presents a set of challenges and opportunities. As this paper has underscored from both academic and industrial perspectives, the next generation of digital communication is not merely about advancing the conventional KPIs, but also to forge a digital ecosystem that is sustainable, inclusive, and trustworthy, in line with the UN's SDGs. We have shown that these values should be related to KVIs, which in turn can be quantitatively mapped to new KPIs. Both synergies and trade-offs will occur, and higher-order effects should be considered. For each of the KVIs, this paper has revealed the intricate nature of 6G positioning and sensing, both to make positioning and sensing coalesce with the KVIs, and to provide services that enhance the KVIs.

As we stand on the cusp of the 6G era, it has become clear that the adoption of a holistic approach is imperative. As researchers, engineers, scientists, and stakeholders, our task is not only to innovate, but also to ensure that the digital future is sustainable, inclusive, and trustworthy.

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