Non-Terrestrial Networks Supporting Internet of Remote Things for Smart Agriculture

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***Abstract*—This work describes the potential benefits that telecommunication networks based on the integration of Non-Terrestrial Networks (NTN) and the Internet of Remote Things (IoRT) paradigm can bring to the development of smart agriculture. All the possible interventions and actions enabled by the synergetic use of these technologies are then described by analyzing the technological aspects and challenges that concern their deployment in rural areas for smart agriculture.**

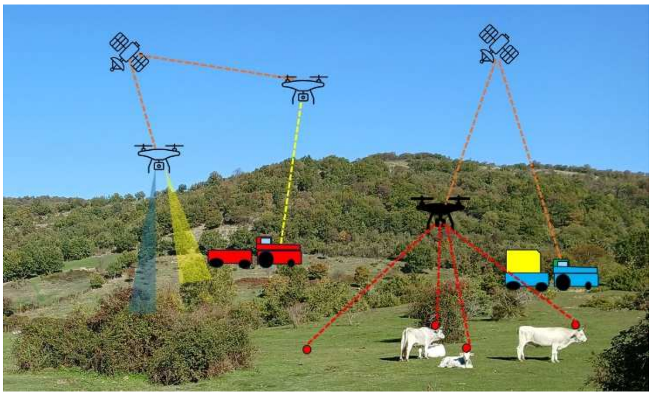
***Keywords*—NTN, 5G, 6G, IoRT, drone, HAP, UAV**

I. INTRODUCTION

Smart agriculture, also known as smart farming, is based on the use of advanced automations that require fundamental support by the telecommunication networks with particular reference to the Internet of Things (IoT). Due to the fact that agriculture is generally made in rural areas, IoT is specifically investigated as of Internet of Remote Things (IoRT) [1]. IoRT refers to a network of smart objects, i.e. sensors and actuators, dispersed over large and remote areas [1]. IoRT devices can be installed when and where needed, but, since agricultural areas generally lack terrestrial network infrastructures, this flood of small communicating objects requires support from Non-Terrestrial Networks (NTN) based on drones and Unmanned Aerial Vehicle (UAV), High Aerial Platforms (HAPs), and satellites. In this scenario, NTNs, and in particular satellite systems, can be the only feasible or efficient solution to provide communication services to all the users located in these areas.

IoRT & NTN can make a fundamental contribution for collecting and distributing data on soil moisture (pH, nutrient levels, water content), environment parameters (temperature, pressure, humidity), and plant health (presence of pests and diseases). In particular, smart agriculture through IoRT devices enables efficient and precise management of agriculture resources, including:

- Optimized use of fertilizers and pesticides, improving plant health.
- Optimized irrigation, avoiding under- or over-irrigation and enhancing sustainability.
- Improved yields by maintaining optimal moisture conditions.
- Greenhouses monitoring and control, adjusting temperature, humidity, and light to optimize plant growth.
- Monitoring and tracking of agricultural products during their storage or transportation.
- Protection against adverse weather conditions.
- Remote monitoring, diagnostics, and control of machinery to support automation in farming.



- Fig. 1: Example of NTN&IoRT for agriculture. IoRTs (red points) communicate with a drone, tractors can communicate both with drones and satellites, drone (on the left) can irrigate and make use of fertilizers.

The data collected and transmitted by IoRT devices can be processed using AI algorithms for real-time or periodic decision-making about irrigation and fertilization and control of product management. In a large agricultural field, the location information of IoRT devices must be transmitted

together with the collected data [2]. Fig. 1 illustrates some examples of NTN&IoRT systems as support for agriculture. This paper analyzes the technological aspects of IoRT and their potential contributions to smart agriculture with their links to NTN, considering the different architectures that can be obtained using drones, HAP, and different categories of satellites.
This paper is structured in the following way. Section II describes some typical NTN architectures, Section III describes the IoRTs with their advantages in rural areas. Section IV is dedicated to the integration of IoRT with NTN for specific agriculture topics, while Section V is dedicated to the future directions. Finally, conclusions are drawn in Section VI.

II. OVERVIEW OF TN-NTN INFRASTRUCTURES

In this Section, we delve deeper into the description of TN-NTN infrastructures to better understand their use and try to give the best support to all those activities that concern the agriculture fields.

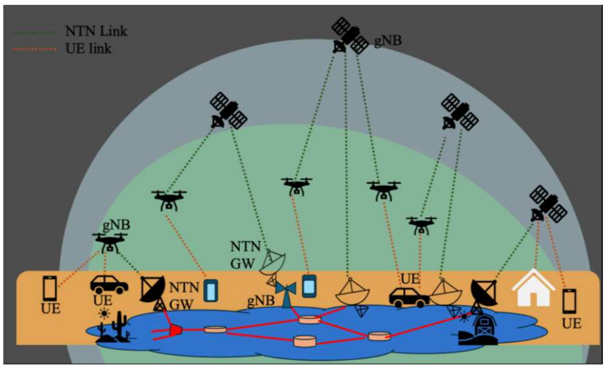


Fig. 2: TN-NTN infrastructures.

The ITA-NTN project focuses on a 6G-oriented framework for 3D wireless connectivity, integrating terrestrial, aerial, and satellite networks, as shown in Fig. 1. The goal is to develop novel methodologies for ubiquitous, on-demand connectivity and edge computing through TN-NTN integration.

Given the distinct transmission roles of each layer, we consider four key architectures.

- Drone-based Relay Network: drones act as flying base stations or relays, enabling communication between distant users and the NTN Gateway (NTN GW);
- Satellite-based Architecture: earth-orbiting satellites provide broad coverage, particularly where terrestrial networks are impractical, though they face latency, cost, and weather sensitivity challenges. It includes two configurations: Satellite-based Access and Satellite-based Backhauling (Integrated Access Backhauling (IAB)-based, introduced in 3GPP Rel. 16);
- 3D Single-Connectivity Architecture: it integrates all entities in various configurations, such as transparent or regenerative modes for satellites and drones (e.g., full gNB or IAB-Donor);
- 3D Multi-Connectivity Architecture: it extends single-connectivity by allowing a User Equipment (UE) to connect simultaneously to multiple NTN accesses (e.g., car on the right in Fig. 2). This enhances network capacity, spectrum efficiency, and reliability [3].

III. INTERNET OF REMOTE THINGS (IORT)

The IoT paradigm consists of a network of nodes that collect sensor data and send control messages to actuators. These nodes possess unique identities, enabling localization, data processing, and interaction with the environment. IoT enhances decision-making, situational awareness, and operational efficiency across various fields.

When IoT nodes are widely dispersed, remote, or difficult to access, they fall under the IoRT. In such cases, satellite communication provides a cost-effective alternative to terrestrial technologies for connectivity. IoRT supports two interoperability modes with satellites:

Direct Access – Sensors and actuators communicate directly with satellites.

Indirect Access – Data is relayed via a sink node, reducing the need for costly satellite terminals.

IoRT applications can leverage:

- Geostationary Earth Orbit (GEO) satellites covering large areas;
- Low Earth Orbit (LEO) constellations offering global or regional coverage, with continuous or intermittent availability.

Below we see some key IoRT applications.

A. *Smart Agriculture*

Also known as precision farming, smart agriculture integrates IoT and data-driven approaches to enhance efficiency, productivity, and sustainability. By leveraging real-time data and automation, farmers can optimize resource use, reduce waste, and maximize yields while minimizing environmental impact. IoRT plays a crucial role in enabling remote monitoring and control of agricultural operations.

B. *Environmental Monitoring*

Disaster Event Detection: Satellites are essential for monitoring environmental hazards such as landslides, avalanches, wildfires, volcanic eruptions, floods, and earthquakes. This requires large-scale wireless sensor networks (WSNs) with:

- Low-cost, easily deployable nodes;
- Minimal maintenance;
- Long battery life (solar-powered where possible).

Wildlife Monitoring: Satellite-based Machine-to-Machine (M2M) systems in the L-band enable wildlife tracking by attaching sensors to animals (see Fig.1). Since these sensors operate in highly dynamic topologies, energy-efficient communication protocols (especially MAC protocols) are essential to minimize costs and maximize efficiency.

C. *Remote Control & Monitoring of Critical Infrastructure*

Critical infrastructure includes vital systems whose failure could disrupt society, economy, and national security. IoRT enhances monitoring and security in key sectors such as:

- Energy (electricity grids, oil, gas pipelines);
- Water (supply, treatment, distribution);
- Transportation (roads, railways, airports, seaports);
- Communication (telecom networks, data centers);
- Finance (banking, stock markets, payment systems);
- Emergency Services (law enforcement, medical response);
- Agriculture & Food Supply;
- Healthcare (hospitals, medical logistics);
- Government Facilities;
- Chemical Industry;
- Nuclear Facilities;
- Critical Manufacturing.

Given their importance, these infrastructures face threats such as cyberattacks, natural disasters, and terrorism. IoRT enables remote surveillance, predictive maintenance, and rapid response strategies to mitigate risks.

D. Smart Goods Tracking

IoRT enhances supply chain management by providing real-time tracking of goods from origin to destination. With IoT-enabled sensors and satellite connectivity, businesses can monitor:

- Location and movement;
- Temperature, humidity, and condition of perishable goods;
- Delays and disruptions in transit.

This ensures optimized logistics, reduced losses, and improved efficiency in global trade and transportation networks.

IV. NTN-BASED SOLUTIONS SUPPORTING SMART AGRICULTURE IN RURAL AREAS

This section presents a description of research fields that have the potential to bring significant advantages to smart agriculture.

A. Network-Side Positioning of IoRT nodes

When positioning services are required jointly with communication services, the presence of Global Navigation Satellite System (GNSS) receivers on network nodes is one of the underlying assumptions [23]. However, for the considered scenario, it should be noted that IoRT nodes are battery-operated devices with minimal chance of charging. Since GNSS receivers are power-hungry, they are inappropriate for such devices. In this situation, localization at the satellite/network represents the most suitable solution. Additionally, when localization is done on the network side, there is no need for sending satellite ephemerides to the IoRT nodes.

In the rest of this Section, network-side positioning of IoRT nodes and satellite-based localization techniques that use the same constellations used for communications are reviewed.

We focus on the localization of IoRT devices using the same LEO satellite constellation used for communication purposes. In order to minimize the complexity and power consumption of IoRT devices, the capability to estimate (compute) the position of the devices must be moved to the satellite system using signals transmitted by the IoRT nodes. This approach, namely network-side positioning, is gaining attention within 3GPP also for non IoRT applications. Initial discussions on network-side positioning have been reported in 3GPP Release 18 in relation to the User Equipment (UE) location verification which has a loose accuracy requirement of 10km [5]. Location verification is fundamental in cellular networks for various reasons such as proper Cell Network selection, but also for regulatory aspects. However, it is recognized that future 3GPP Releases will focus more on network-side positioning via LEO satellites to replace or complement the current GNSS-based solutions [5]. Therefore, it is of utmost importance to start understanding the available options for LEO-based positioning in the integrated TN-NTN scenario, in particular for what concerns the integration of communication and localization services within the same system. Several works have recently proposed novel network-side positioning algorithms for IoRT nodes. In [6] a novel positioning algorithm based on a single-antenna-equipped single-satellite has been presented. The proposed scheme involves measuring both Round Trip Time (RTT) and Doppler shift for precise node localization. This approach allows us to use the same signals and data packets for both communication and localization.

The idea of the work presented in [7] was to study the feasibility of utilizing NTN communication protocols for positioning in terms of ranging accuracy, Receiver Operating Characteristics (ROC), and Mean Acquisition Time (MAT). The study focused on 5G-NR and DVB-S2X communication standards, quantifying the effects of design parameters and resource allocation.

B. Satellite-edge computing supporting IoRT nodes

A wide range of emerging services in smart agriculture, such as smart irrigation, disaster risk reduction, product traceability, and post-harvest, require the execution of computation-intensive and time-sensitive tasks, which IoRT devices are not able to accomplish due to their limitations in terms of computing and energy resources.

A widely adopted approach is to utilize ground-based data centers, leveraging the edge computing paradigm. However, in the case of insufficient or unavailable terrestrial infrastructure, such as in the case of rural areas where IoRT for smart agriculture is likely to be deployed, the provision of sensing, communication, and computing resources is crucial for remotely monitoring the area, managing critical conditions, and implementing appropriate actions.

A significant recent innovation in the field of satellite communication is undoubtedly the family of miniaturized satellites known as CubeSats because of their basic cubic shape. In recent years, CubeSats have been integrated into novel architecture leveraging emerging networking paradigms, such as the Internet of Space Things (IoST) [8]. LEO satellites play a crucial role in backhauling for 5G networks [9] and contribute to the implementation of Cloud-RAN, facilitating reliable wireless connectivity in challenging environments [10].

While LEO satellite constellations are primarily used to provide global Internet access, their enhanced processing capabilities have driven research into LEO satellite edge computing [11]. Leveraging the computing capabilities of LEO satellites to implement an orbital computing continuum for equal access to computing is envisioned via simple scheduling techniques in [12]. The integration of edge computing into LEO networks is examined in [13], where the potential functionalities of a LEO-based edge computing prototype system are assessed in comparison to cloud computing.

Authors in [14] propose a Satellite Mobile Edge Computing (SMEC) framework designed for real-time, high-resolution Earth observation, optimizing image distribution and compression to reduce energy consumption. In [15], a distributed service deployment framework is introduced for satellite edge computing networks, aiming to optimize resource allocation while minimizing service processing delays for time-sensitive applications.

Several studies [16]-[18] have explored multi-tier edge computing architectures. Reference [16] introduces a three-tier computation model incorporating ground users, LEO satellites, and cloud servers, where task offloading decisions are optimized to minimize ground users' total energy consumption. In [17], a satellite-terrestrial edge computing framework is proposed, outlining key principles and functionalities for MEC deployment in hybrid networks. Additionally, [18] formulates a joint communication and computation resource allocation problem within a LEO-assisted satellite edge system, focusing on overall energy dissipation minimization.

C. NTN-based solutions for computation offloading

The adoption of cooperative strategies in satellite systems offers significant advantages across various application domains. Federated satellite systems provide notable benefits by enabling resource sharing among satellites to enhance overall system efficiency [19]. In [20], a 5G satellite-IoT platform integrated with virtualization and edge computing capabilities is developed, allowing virtualized CubeSat constellations to collaborate and operate under the supervision of terrestrial edge nodes for IoT service delivery. The study in [21] focuses on optimizing a cooperative edge-cloud offloading model to reduce total latency in a combined satellite-terrestrial network, deriving an optimal task allocation strategy with a closed-form solution. Leveraging digital twin (DT) technology, [22] introduces a digital twin-driven satellite-terrestrial collaborative computing framework consisting of terrestrial users, base stations, LEO satellites, and a cloud center. In this system, terrestrial users' computational tasks can be partially offloaded to the base station's edge server, the linked LEO satellite edge server, or a neighboring LEO satellite edge server.

V. CHALLENGES AND FUTURE DIRECTIONS

The reviewed literature underscores the significant research efforts directed toward NTN-based solution for positioning and computation offloading. However, a set of open challenges need to be faced in order to exploit their potential in rural areas for smart agriculture.

On the network-side positioning of IoRT nodes, novel algorithms have been proposed and their performance evaluated. However, it must be considered that network-side localization moves most of the computational burden on the satellite, which might be LEO satellites with limited resources and payloads. Therefore, the reduction of the computational complexity of any solution should also be taken into account. More in general, direct-connectivity of IoRT would be extremely important and it is still one of the main challenge. In this framework, concepts like distributed satellite systems and multi-satellite MIMO are currently under investigation.

Regarding NTN-based computation offloading, we identify a set of challenges as having key importance and, thus, to be considered in the investigation of future solutions. First of all, CubeSats often face limitations in computing, storage, and sensing resources. Consequently, enabling task offloading between satellites can significantly enhance overall task execution capability. In addition, space-to-ground latency can pose significant challenges for latency-sensitive applications. Moreover, the multi-tenancy issue needs to be tackled as the satellite network in the sky can be composed of Cube-Sats equipped with heterogeneous payloads and belonging to different constellations owned by different tenants. To solve all mentioned challenges, we envision that an effective solution to be realized in the multi-tenant IoT satellite scenario facilitating the delivery of smart agriculture services is exploiting cooperation strategies among space nodes with onboard computing/sensing/storage resources and, at the same time, leveraging the possibility of utilizing the resources of neighboring satellites reachable via ISLs to realize an effective computing center in the sky, thus improving task execution while reducing service delay.

VI. CONCLUSIONS

We have illustrated that the combination of NTN and IoRT are a fundamental support for smart agriculture. In fact, it has the potential to revolutionize farming by enhancing efficiency, reducing waste, and increasing profitability. From AI-driven plant analytics to automated irrigation and fertilization, IoRT-based solutions help farmers make data-driven decisions that boost productivity while ensuring sustainability. This represents the future research directions.

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