

Realizing Challenging Internet of Things Applications Via Aerospace Infrastructures

Emmanouel T. Michailidis^{1,2}, Stelios M. Potirakis², and Athanasios G. Kanatas¹

¹Department of Digital Systems, University of Piraeus, Piraeus, Greece
e-mail: {emichail, kanatas}@unipi.gr

²Department of Electrical and Electronics Engineering, University of West Attica, Campus 2, Aigaleo, Athens, Greece
email: spoti@puas.gr

Abstract—This paper intends to justify why the aerospace communications is a key technology that will bring the Internet of Things (IoT) vision closer to reality. Both satellites and aerial platforms, such as High-Altitude Platforms (HAPs) and Unmanned Aerial Vehicles (UAVs), are considered. Their advantages are highlighted mainly in terms of the radio coverage and the link reliability, and their potential applications in several sectors are described. Emphasis is also given on the advanced wireless technologies that can further enhance the capabilities of aerospace communications.

Keywords—High-Altitude Platforms (HAPs); Internet of Things (IoT); satellite networks; Unmanned Aerial Vehicles (UAVs).

I. INTRODUCTION

The Fifth-Generation (5G) vision does not only represent a significant upgrade of mobile broadband communications, but it will bring new unique network and service capabilities towards the evolution of Internet of Things (IoT) [1]. The IoT is an information network that encompasses a large family of smart and critical applications and supports a massive number of small, low-cost and low-power interconnected physical objects, generally referred to as Machine-Type Devices (MTDs), which interact and cooperate without human intervention, in order to reach common goals. More specifically, the IoT comprises sensors and actuators interacting with data processing, wired and short- and long-range wireless communication technologies, ground-based processing, and humans.

The successful operation of IoT-based networks envisages the seamless and synergetic integration of heterogeneous terrestrial and aerospace networks with different capabilities, which give rise to new services, architectures, and challenges [2]-[4]. From a communications engineering standpoint, the heterogeneity of the aforementioned technologies translates into highly different service requirements in terms of data traffic, end-to-end communication delay, reliability, etc. Cloud and fog computing and networking can facilitate the seamless integration of different heterogeneous networks, whereas Software-Defined Radios (SDR) and Software-Defined Networking (SDN) could bring flexibility and support the cost-efficient deployment and runtime of customized networks [5]. Motivated by these observations, this paper

tries to shed light on the aerospace-based IoT and describe its special characteristics and the benefits provided by the aerospace infrastructures.

The rest of the paper is organized as follows. Section II describes the types of aerospace communication technologies. Section III underlines the advantages of satellites and aerial platforms, while Section IV presents the advanced wireless technologies that intend to enrich their capabilities. Section V outlines the potential applications of aerospace-based IoT. Finally, conclusions are drawn in Section VI.

II. TYPES OF AEROSPACE COMMUNICATIONS

Hybrid satellite-terrestrial networks are a typical example of cooperation between different architectures [2]. As the demand for comprehensive broadband and broadcast/multicast high-speed wireless communication services (e.g., voice, data, and multimedia services), global coverage, and ubiquitous access has grown, satellite networks can strongly support terrestrial backhaul networks and provide extensive as well as uninterrupted radio coverage to stationary, portable, and mobile receivers at frequencies ranging from 100 MHz to 100 GHz, as well as at optical frequencies, using different orbital architectures. Satellite are spaceborne vehicles capable of bringing communications to sparsely populated or underdeveloped areas, and still maintaining exclusive status in traditional maritime and aeronautical markets from the wide area perspective due to their unique coverage features.

In recent years, the use of mobile airborne services via aerial High-Altitude Platforms (HAPs), i.e., airships powered by solar cells or aircrafts powered by fuel engine propulsion, flying in the stratosphere, and Low-Altitude Platforms (LAPs) or Low- and Medium-Altitude Platforms (LMAPs) flying at various altitudes in the troposphere to supplement wireless terrestrial infrastructure has been also suggested [6]. The latter includes the Unmanned Aerial Vehicles (UAVs), i.e., Remotely Piloted Vehicles (RPVs), drones, robot planes, and pilotless aircrafts [7]. These platforms are capable of providing ubiquitous wireless access over large coverage areas at low cost, while they attain network flexibility and adaptability due to their rapid deployment and movement on demand. Project Loon initiated by Google has intended to leverage high-altitude balloons for broadband services in remote locations [8], whereas Facebook [9] has attempted to

deploy solar-powered drones to provide Internet access to underdeveloped areas. Moreover, Microsoft has deployed balloons in the stratosphere loaded with sensors and cameras, which are connected to the Azure IoT platform and send the telemetry to the field gateway through the Constrained Application Protocol (CoAP). Figure 1 demonstrates a hybrid communication network consisting of terrestrial and aerospace infrastructures for IoT applications.

III. ADVANTAGES OF AEROSPACE COMMUNICATIONS

By leveraging the aerospace platforms, the IoT connectivity can be enhanced based on the additional communication choice. High-speed geostationary and/or non-geostationary satellites can provide efficient backhauling of aggregated IoT traffic from multiple sites and transfer data from Low-Power Wide Area Network (LPWAN) devices to applications on cloud platforms. They can also enable multicast/broadcast and trucking of video, IoT and other data across a large coverage area or a central site, with further terrestrial distribution to local cell sites. The aerospace communications have the potential to promote the Internet of Remote Things (IoRT) [10] in locations with terrestrial network constraints, i.e., remote, highly mobile, highly dispersed or wide geographical areas (rural, maritime, aero, railway, vehicular), and support massive Machine-to-Machine (M2M) communications. The aerospace infrastructure is not only capable of interconnecting remoted or dispersed smart objects, but also ensuring effectual management of data-intensive applications, redundant connections at critical sites, reliability, low latency, and enhanced capacity. A typical example of IoRT is the Global Sensor Network (GSN) for remote environment observation, where massively connected IoT sensor networks are connected via Low Earth Orbit (LEO) satellites.

Satellites have a major role in assisting 5G networks to meet sub-1ms latency requirements by delivering commonly accessed content to mobile base stations and multi-casting content to caches located at individual cells, even in places without fiber. Although Geostationary Earth Orbit (GEO) satellites latency of 250 ms (500 ms round-trip) is acceptable for many 5G and IoT applications and is comparable with the RTT of a long terrestrial link (100-200 ms), Medium Earth Orbit (MEO) and LEO satellite constellations allow for meeting more stringent latency requirements in case of voice and video transmission.

The aerospace platforms are not only an important supplement for big data acquisition methods for IoT, but also can improve the network performance. Since the links of terrestrial systems are often blocked, the aerial platforms, especially HAPs and drones, have great potential to attain a higher chance of Line-of-Sight (LoS) communication with the ground users and thus enhance the coverage and connectivity. The UAVs can also easily move, have a flexible deployment, and can provide rapid, on-demand communications. The realization of IoRT and M2M communications can be further reinforced due to the investments in new ground segment technologies, such as small, electronically steerable, electronically steerable, and/or phased-array satellite transceivers, as well as the cost-

effective CubeSat platforms [11] based on micro, nano- and pico- satellites, operating as access points.

IV. ADVANCED WIRELESS TECHNOLOGIES

Although the local connectivity in IoT is provided by means of a short-range radio access technology, i.e., Bluetooth Smart, ZigBee, IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN), and Z-Wave, long-range wireless connectivity can be achieved using conventional, i.e., cellular and satellite networks, or LPWAN technologies, e.g., Long Range (LoRa), Sigfox, Ingenu, and Narrowband-IoT (NB-IoT) [12]. In the context of satellite-based IoT applications, Inmarsat was the first to join the LoRa Alliance as its first satellite member and combine a LoRa Wide Area Network (LoRaWAN) on the ground with a satellite mesh in the sky. Inmarsat and other service providers predominantly use the lower data rate L-band (1-2 GHz). While L-band systems will continue to support extremely low data-rate IoT applications, higher frequencies, e.g., the Ka- and Ku-bands, are positioned for future applications, as network traffic increases. With Ku-band, service providers can leverage the large number of open Ku-band satellites, which traditionally offer lower spectrum cost than L-band. Although using Ka- and Ku-bands may be beneficial, rain effects severely affect signal propagation in mm-wave frequencies and a strong, dominant LoS signal is required for sufficient coverage due to the severe attenuation of the Non-Line-of-Sight (NLoS) links.

The capabilities of aerospace networks in terms of the latency are in part due to the use of Adaptive Coding and Modulation (ACM) techniques as foreseen in the Digital Video Broadcasting – Satellite – Second Generation (DVB-S2) standard, which retains outbound throughput even during heavy weather conditions. To further improve the performance of aerospace systems, algorithms based on cognitive radio principles can be applied that enable dynamic spectrum access and agile waveform adaptation (from carrier aggregation to unlicensed spectrum sharing).

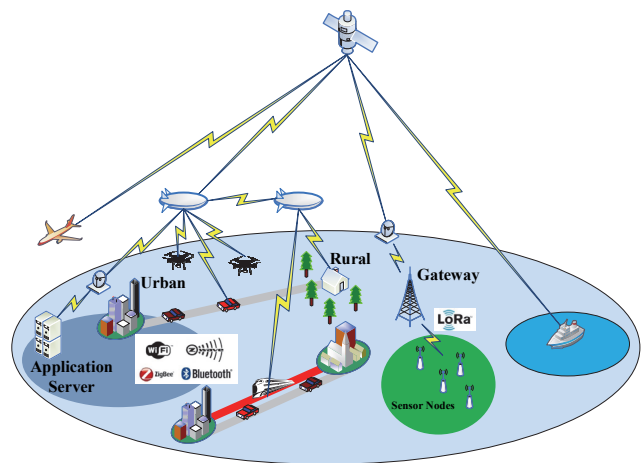


Figure 1. A simple representation of an hybrid terrestrial-aerospace communication network for IoT applications.

To successfully fulfill the growing demands for high data throughputs and enhanced link reliability with greater mobility support and extended network range, cooperative diversity preserves the end-to-end communication between a source and a destination via intermediate relays [13]. Since new requirements for enhanced spectral efficiency, greater bandwidth and higher data rates emerge, the Multiple-Input Multiple-Output (MIMO) [14] [15] and massive MIMO [16] technology can revolutionize satellite networks, exploit spatial diversity, and serve multiple users (i.e., multi-user MIMO). This has gained great interest due to the standardization activities on the finalized DVB - Satellite to Handheld (DVB-SH) standard [17], and the prospective DVB - Next Generation Handheld (DVB-NGH) [18] standard. As the performance of radar systems is limited by target scintillations, the application of MIMO techniques to Synthetic Aperture Radars (SARs) can greatly improve resolution and sensitivity, as well as detection and estimation performance of aerospace applications for the IoT by exploiting the diversity of target scattering [19].

Data rates in the multigigabit regime can be achieved using Free-Space Optical (FSO) inter-satellite, inter-platform, satellite-to-ground, and platform-to-ground connections [20]. Compared to Radio-Frequency (RF) systems, FSO systems are capable of providing intrinsic narrow beamwidth and high-speed LoS connectivity using the wavelength division multiplexing scheme with very small and compact equipment and low power consumption. In addition, FSO systems ensure privacy with low probability of interception, immunity to electromagnetic interference, and exemption from spectrum regulatory restrictions.

V. POTENTIAL APPLICATIONS

It is important to note that the notion of IoT comprises a wide variety of applications. The challenging ones that will be benefited by the aerospace infrastructures refer to the critical IoT and require very high reliability and availability in terms of wireless connectivity. Although the average volume of data transported to and from devices may not be large, wide instantaneous bandwidths are useful in being able to meet capacity and latency requirements. On the other hand, the low cost of the devices and the energy consumption is not as important as for other IoT applications. Typical paradigms of critical IoT applications are the following:

- **Transport Applications:** The aerospace communications can improve the safety and management of transportation infrastructure and realize the Internet of Vehicles (IoV) [21]. Specifically, an expanded adoption of networking vehicles, sensors and controls can be achieved that will enable the smarter use of road and rail transportation by effectively supporting applications such as, signage, signaling and routing, alerts for road and weather conditions, level crossing protection, and train control systems. Satellite-based Global Positioning System (GPS) can determine the

positioning of each vehicle, whereas HAPs represent a feasible solution for data acquisition in IoV, especially in rural areas. Besides, monitoring of vehicular traffics through drones with embedded cameras or sensors is also viable. By taking advantage of the aerospace infrastructure, the operation of commercial autonomous shipping can be enabled along with future commercial marine vessels, cargo logistics, and smart ports [22].

- **Industrial Applications:** The aerospace networks can also play a key role in a sub-segment of the IoT, referred to as the Industrial IoT (IIoT) [23], since they can deliver connectivity to remote locations and challenging environments. Although satellite networks are extensively deployed to support critical Supervisory Control And Data Acquisition (SCADA) applications, IIoT can be seen as an expansion of SCADA networks and other global asset tracking applications, remote control, automated fabrication, collaborative robots, etc. Applications tend to be those involving remote locations or extending over large land or sea areas, such as water level monitoring, oil and gas pipeline integrity, and tracking of mining trucks. Overall, the IIoT market seems a significant opportunity for satellite service providers.
- **Medical Applications:** The satellites and the aerial platforms combined with information and cloud technology are playing an increasing role in the support of welfare and Healthcare IIoT (HealthIIoT) applications [24] and can be used for providing low-cost and timely healthcare in remote and inaccessible areas. These technologies have a profound effect on the quality, safety, and efficiency of healthcare. The patients and the aging society can be served by satellite based telemonitoring, medical diagnosis and care from their homes, whereas interaction through videoconferencing between medical personnel and patients at home can be obtained. Moreover, using biomedical sensors, collection and transmission of medical data is feasible. Aerospace communications can also be used for monitoring endemics/epidemics at any area, while high bandwidth links can accommodate real-time medical imaging and remote robotic surgery [25].
- **Disaster and Crisis Management Applications:** As the natural disaster or large-scale unexpected events easily make the terrestrial network overloaded or totally destroyed, hybrid satellite-aerial-terrestrial networks have the ability to provide more effective services compared to traditional infrastructures during the emergency situations. Aerospace networks can offer rapid deployment and wide coverage and successfully support applications, such as video surveillance, structural monitoring and protection of critical infrastructure [26]. These include dams, bridges and other important structures,

as well as security and access controls related to border control, flood warning, earthquake detection, weather and environmental monitoring, coastline and pipeline surveillance, trafficability of maritime routes, e.g., icebergs, and synthetic aperture radar applications. The emergence of LAPs indicates a stable and reliable direction for the development of emergency network via circular flight tracks and continuous observation of regional hotspots and hazard areas.

- **Smart Energy Applications:** The aerospace infrastructure can efficiently handle a variety of electric grid automation and metering applications and support the integration and efficient use of all the energy resources and the grid infrastructure, using smart sensors, smart meters and smart control [27]. Moreover, there exists a wide range of applications in oil and gas that the aerospace infrastructure can effectively enable. These include monitoring and transmitting sensor data concerning drilling control, wellhead production, pipeline monitoring, distribution logistics and asset security.

VI. CONCLUSION

In this paper, the role of aerospace communication technologies in the future IoT ecosystem has been described. Since ubiquitous connectivity and long-range radio coverage are required in many critical IoT applications, satellites and aerial platforms along with advanced 5G wireless technologies can drastically change the landscape of various industries and strongly support the evolution of IoT.

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