Drone Networking in 6G Era - A Technology Overview

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***Abstract*—Sixth generation (6G) wireless communication networks are envisioned to be empowered with novel enabling technologies to guarantee ubiquitous coverage requirements, heterogeneous communication scenarios, improved network intelligence, spectral rates and security. 6G vision is not only limited to terrestrial networks, but also extends to non-terrestrial networks encompassing satellites and aerial networks, thus exploring a full spectra of heterogeneous communication links.**

In 6G scenarios, the role of Unmanned Aerial Vehicles (UAVs) is of paramount importance, as flying devices are expected to densely populate aerial space, providing an intermediate network layer between ground networks and space ones. As a vision of fully integrated 6G heterogeneous networks, ground, aerial and satellite networks will coexist, thus realizing space-air-ground integrated communication network for 6G scenarios. This work highlights several novel 6G enabling technologies, and presents the detailed study and evaluation of communication technology candidates from the perspective of aerial communication networks, key design considerations and technical challenges.

I. Introduction

While the fifth generation (5G) mobile systems are being deployed all over the world, academia and industry are already focusing on the demands and constraints that novel futuristic use-cases will require from beyond 5G (6G) systems. Insistence for high data rates, low latency, massive connectivity, ultra-reliability, and high devices density are key requirements reinforcing novel services for virtual/augmented reality (VR/AR), autonomous cyber-physical systems, smart infrastructures, multi-sensory holographic teleportation, real-time remote healthcare, high-performance precision agriculture, reactive disaster management, and space connectivity [1].

To cope with such strict requirements, the initial directions undertaken by communication practitioners can be summarized into four main research lines *i.e.*, (*i*) new ways of using the spectrum and, consequently, (*ii*) new paradigms of designing the radio, (*iii*) highly reconfigurable, intelligent and autonomous network architectures, and (*iv*) larger network connectivity areas, extended to near-Earth and deep-space. The mentioned research directions can be assembled into a novel mobile communication paradigm that will represent researchers' challenges for the next years: the 6G [2].

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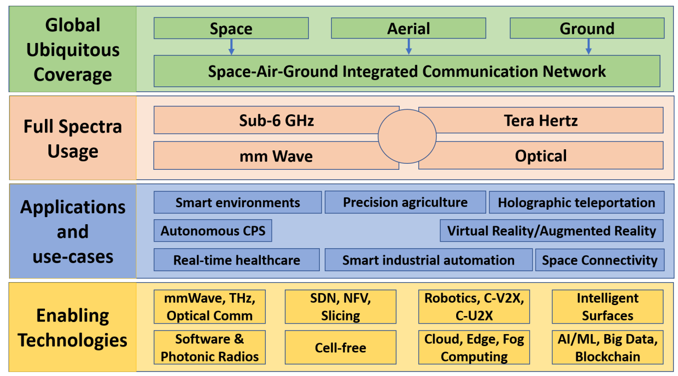


Fig. 1: Synergy of Drone Networking with 6G Vision.

In the vision of this paper, a key architectural and operational element for 6G communications is integration of UAVs (also interchangeably referred as "drones" in this work). Unsurprisingly, UAVs have already been tested for harmonious integration with 4G, 5G networks and endorsed by standardization bodies (*i.e.*, 3GPP, IEEE, ITU) as an essential part of 5G and beyond networks. However, their real potential would be unleashed only by extending connectivity links to space network (*i.e.*, satellites, high-altitude platforms), thus generating an *integrated space-air-ground communication network*.

Towards the fulfillment of this grand vision, the objective of this paper is to explore the synergistic trends of UAVs within 6G systems, with a special focus on *(i)* global ubiquitous coverage, *(ii)* full-spectra usage, *(iii)* diverse applications and use-cases, and *(iv)* enabling technologies, as summarized in Fig. 1. The need to reach a **global ubiquitous coverage** establishes the connectivity of the future via universal and seamless accessibility. Through inter-working of ground, air and space network segments, the convergence advantages from different segments can be exploited to support multifarious UAV applications and services in an efficient and cost-effective manner. To this aim, 6G envisions **full spectra usage** through new spectrum-use methods with multi-band high-spread spectrum, as well as high frequency bands including Sub-6 GHz, Millimetre Wave (mmWave), Terahertz (THz), and even optical frequency band to allow high date rate transmission links. The aforementioned **diverse applications and use-cases** that would benefit from the introduction of UAVs into 6G systems have shifted the vertical industries towards data-driven dynamic and intelligent service models to offer "fully immersive experiences" and "anything or everything-as-a-service" paradigms.

Such innovative models and paradigms are then requiring novel **enabling technologies** that are developed with attractive potentials. The key drivers include Artificial Intelligence (AI) and Machine Learning (ML), Blockchain and big data technologies for information security, automatization, and network intelligence. Also, new technologies like those in mmWave, THz and optical frequency bands are expected to provide higher spectral efficiency, as well as cell-free communications to ensure seamless connectivity and handovers, and intelligent reflecting surfaces for proactive radio signal control. Furthermore, the need for softwarization and programmability of network service deployment has pushed advances in slicing, network function virtualization (NFV), software-defined networking (SDN) and cloud technologies. Finally, photonics radios are expected to offload the complex signal processing to photonics chip and spectrum mining, while Cellular Vehicle (UAV)-to-everything (C-V2X or C-U2X) paradigm is an enabler to connected robotics for intelligent device access and autonomous provisioning.

Contributions: Keeping in mind the 6G vision and requirements, the main contributions of this paper are as follows:

- We define and characterize the "aerial network" segment within an *integrated space-air-ground communication network* (in Section II) ;
- We explore six enabling technologies through their advantages/drawbacks and their integration path within a UAV-enriched 6G system (in Section III);
- We present the standardization progress for each of the enabling technologies along with the open research challenges (in Section IV).

II. Space-Air-Ground Communication Network

The 6G wireless systems are envisioned to provide full-spectra support for diverse and multiple Radio Access Technologies (*i.e.*, multi-RATs). 5G standardization already includes the integration of heterogeneous networks, such as 5G with satellites or UAV network. However, the comprehensive methodologies for integrated space-air-ground overlapping layers have not been fully investigated. Driven by such need, this paper describes feasible approaches for space-air-ground network integration and sheds light on research efforts to embrace multi-dimensional and inter-operational network of 6G vision. This section highlights the three network segments and emphasize the role of "aerial" segment as an intermediate layer, between the ground and the space, empowering global ubiquitous coverage as shown in Fig. 2.

The links connecting the ground (terrestrial) network with aerial ones facilitate **ground-to-aerial (G2A)** and **aerial-to-ground (A2G)** communications complimenting wireless broadband access of the ground infrastructure [3]. Such cross-layer inter-working is the most advanced in terms of deployment of existing and standardized solutions. 3GPP Rel-15, envisions UAVs with potentials of supporting high transmission capacity ($\sim$ 10 Gbps), stringent latency (1 ms round trip delay), user traffic offloading and enhancements to RATs. Furthermore, 3GPP Rel-17 identifies requirements and key performance indicators (KPIs) for multitude of use-cases

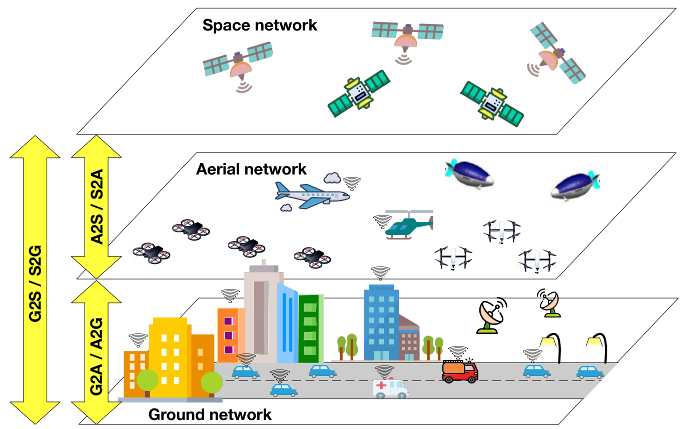


Fig. 2: Integrated space-air-ground network in 6G scenarios.

with reliable and beyond visual line of sight (BVLoS) UAV operations.

The "space" segment encompasses satellites and deep space communication equipment. Satellite communication backbone (SATCOM) is centered on earth expanding to different orbital depths of the universe [4]. Typical SATCOM backbone network consists of low earth orbiting (LEO), middle earth orbiting (MEO) and geosynchronous earth orbiting (GEO) satellites relaying information to the "ground" network segment. SATCOM enables satellites in different orbits to meet differentiated services quality. SATCOM links are stable, possess anti-destroying ability with global coverage. However, expensive infrastructure, large propagation distance, and high latency links are main challenges of this segment. Cross-layer inter-working between "space" and "aerial" segment is a viable solution in the form of **space-to-aerial (S2A)** and **aerial-to-space (A2S)** transmission links which can supplement in relaying information from satellites to "aerial" and in turn to "ground" segment. LEO and GEO satellites, operating at 2000 and 35000 km height, respectively, are the two most used technologies for S2A/A2S communications, and offers cost-effective and backhaul-aware transmissions to HAPs [5].

The "aerial" segment is a cardinal layer in realizing the multi-dimensional and inter-operational network of 6G vision due to its ability to effectively glue between other two layers separated by thousands of miles. Commercial multi-rotors, fixed-wing UAVs, balloons, and airships are constituent infrastructures functioning as high or low altitude platforms (HAPs or LAPs) in this segment. In contrast to SATCOM, HAPs operate with lower transmission delay, lower cost, easy mobility in emergency situations, broad coverage with high elevation angles. Existing works already depict inter-working between SATCOM and HAP for robust beamforming or enhancing communication secrecy. In situations where HAPs are not preferred due to high cost in generic civilian applications (*e.g.,* temporary hot-spots, sports event), LAPs acts as a connecting link to ground devices. The LAPs in turn might bridge the connection to HAPs and further to space segment, thereby creating opportunity for end-to-end connectivity from ground device to space network.

Increasing use of UAVs by private users is bringing concerns for accidental misuses. Specific standards and regulations for making UAVs' usage safer are therefore necessary. Since multiple UAVs may form a swarm allowing to overcome the individual UAV limitations pertaining to on-board battery and computation, UAV-to-UAV (U2U) or **aerial-to-aerial (A2A)** collaboration has to be considered. A2A in real-world critical missions is a complicated problem due to frequency regulations related to the security of the airspace-sharing. Current solutions for A2A communications are based on the use of license-free, unreliable frequency band, thereby mandating to leverage alternative licensed frequencies, in order to make the swarm connectivity and communication more secure and reliable. For instance, the Ultra-High-Frequency (UHF - 400 MHz) can be a promising solution for A2A connectivity, subjected to specific requirements related to the communication environment considered, *i.e.*, low impact of obstacle diffraction, lower impact of distance in respect of Wi-Fi frequencies.

III. Full-Spectra Candidate Technologies

Candidate technologies such as mmWave or sub-6 GHz are widely studied, and their performance is already evaluated for 5G communication systems. While these technologies mark key advancements towards higher spectral efficiency, 6G wireless network necessitates further exploration of access networks and communication links to meet its multifarious vision. Specifically, we have envisioned massive MIMO, mmWave, THz, Sidelink, Free Space Optics (FSO), and Visible Light Communications (VLC) as the main technologies for 6G scenario. This section summarizes each technology in terms of (*i*) main features, (*ii*) standardization progress, (*iii*) integration with UAVs, and (*iv*) main advantages and drawbacks.

A. Massive Multiple Input Multiple Output (MIMO)

Technology overview: Massive MIMO is a compelling sub-6 GHz physical layer wireless access technology and a key enabler of multi-antenna multi-user cellular communication possessing with three main features *i.e.*, (*i*) array gain that helps in coverage extension, (*ii*) spatial multiplexing serving many terminals in same resource block and (*iii*) supporting high mobility via time division duplex (TDD) and channel reciprocity. Moreover, for aerial and space LoS communication, massive MIMO performs well along with rich scattering. In urban environments, antenna array mounted on high-rise buildings provide ubiquitous coverage for UAVs.
Standardization progress: 3GPP release 13 and 14 specifies a beam-based NR (new radio) air-interface in which 16 to 32 antenna elements are used as massive MIMO. Release 15 further enhances to 64+ antenna elements to support more complex and efficient processing for capacity extension.
Integration with UAVs: In case of cellular-connected drones controlled by a central base station, massive MIMO facilitates reliable A2G and G2A transmission links. Unlike ground UEs, drones move in 3D space, the flight dynamics tend to change to antenna polarization and gains with time, thus making the continuous connectivity very vulnerable. Furthermore, UAVs possess less multi-path propagation and hence, result in frequent polarization mismatch events. Massive MIMO is instrumental in solving issues pertaining to 3D UAV mobility by exploiting more antennas for robust signal processing [6].
Advantages and drawbacks: Massive MIMO offers high throughput communications for UAVs to quickly cover large geographical regions. The primary challenge in massive MIMO based deployment is the design of efficient MAC layer and interference management. Moreover, the antenna array geometry of the ground station, flying speed, and altitude of UAVs complicate the propagation environment, as well as the spectrum management for drones.

B. Millimetre Wave (mmWave)

Technology overview: The mmWave frequencies will play a key role in 6G vision because of the availability of high bandwidth (in $30-300$ GHz range) supporting high data rate (nearly 10 Gbps) aerial communication. Shorter mmWave wavelengths are also beneficial for UAV operation, resulting in smaller circuits and antennas. In terms of security and interference, mmWave frequencies are immune to channel disturbances because of highly directional beams and high resolutions that make the signal interception really hard.
Standardization progress: The standardization activities by IEEE and 3GPP for mmWave are still in their initial stages and 3GPP/IEEE compliant standardization proposals towards solving current challenges of mmWave are also missing. There have been some contributions by 3GPP RAN1 group with focus on the mmWave waveform designs and MIMO performance such as interference analysis in the range between $24.25-86$ GHz, cyclic-prefix (CP) types over 6 GHz etc.
Integration with UAVs: mmWave is considered as a preferred candidate for UAV-assisted cellular networks (*e.g.*, flying base stations, relays) than lower microwave frequencies because of notable coverage and capacity enhancements for ground users.
Advantages and drawbacks: The key advantages of mmWave-based communications are attributed to availability of higher channel bandwidth that translates to higher data rates, smaller wavelength that encodes more information in less time, presence of narrow beams that are preferred for secure and sensitive message transmission with better interference control schemes. Despite of several advantages, primary challenges for mmWave frequencies are related to beam misalignment, high path loss and atmospheric attenuation. Moreover, harsh weather conditions (*i.e.*, rain, absorption by water vapors, oxygen) degrade the mmWave channel.

C. Terahertz (THz)

Technology overview: 6G requires specific applications to handle large amount of data as well as very high throughput per devices (Gbps to Tbps), and per area efficiency (bps/km^2). In this context, THz technology is envisioned to surpass the gap between the mmWave and optical communications band.
Standardization progress: In 2017, IEEE 802.15.3d-2017 is published as the first wireless communication standard operating at carrier frequencies around 300 GHz [7]. It focuses on fixed point-to-point links, and refers to applications as intra-device communication, kiosk downloading, complementary

links in data centers and backhaul/fronthaul links. Furthermore, at IEEE 802.15, the THz Interest Group is actively working towards identification of further additional applications, which would require a further amendment of the current standard. In terms of spectrum for THz communications the radio regulations allow the use of spectrum beyond 275 GHz.

Integration with UAVs: At higher altitudes above 16 kilometers, the impact of environmental moisture is not significant and therefore, THz is mainly envisioned HAPs. Furthermore, THz is a suitable alternative for environments with high UAV mobility. High mobility UAVs are less affected by Doppler effect in a high carrier frequency setting like THz. THz communications can establish high-speed communication links through the selection of the optimal beam pattern. THz MIMO-OFDM system between two UAVs can be used to estimate the UAV position and orientation. As a result, millimeter-level positioning accuracy has been shown to be reachable if the transmitter-receiver separation is sufficiently small. UAVs also need short-distance secure links to receive instructions or transmit data before dispersing to fulfill their remote controlled or autonomous missions. Extremely narrow beams (pencil-beam directionality) reduce the probability of eaves-dropping. In this context, the large channel bandwidth of THz allows for specific protection measures against various attacks like jamming. THz links could be also utilized between UAVs and airplanes, and for HAPS acting as a relay node in the sky linking ground station and airplane.

Advantages and drawbacks: THz-band offers many benefits as described in previous subsection and represents a promising solution to current spectrum crunch. However, THz channels in outdoor environment experience significant loss due to molecular absorption and weather conditions. Interestingly, concentration of the water vapor molecules decreases at higher altitudes (e.g., HAPs) enabling the communication over the THz-band to be more feasible as compared to ground network.

D. Sidelink (Device-to-Device or D2D)

Technology overview: 3GPP release 12 started its normative efforts in development of a new feature, "sidelink" to enable direct transmission between two devices bypassing the base station infrastructure. It is continued in the subsequent 3GPP releases as "proximity services (ProSe)". Emerging applications of sidelink proximity services include public safety, vehicle-to-vehicle (V2V) communications, content offloading and distribution etc. Empowered by sensing-based semi-persistent scheduling (SB-SPS) and use of dedicated licensed physical channels for sidelink transmission, it is envisioned as a strong candidate to perform V2V or U2U communication.

Standardization progress: 3GPP's enhancements for vehicle-to-everything (V2X) communication (a.k.a. eV2X) using sidelink [8] focus on four areas: (*i*) vehicle platooning, (*ii*) advanced driving, (*iii*) extended sensors, and (*iv*) remote driving. eV2X supports mutual information exchange within the vehicle platoon; this concept greatly contemplates aerial swarm control and communication. Advanced driving leverages the freedom of inter-vehicle signaling to coordinate cooperative, safe vehicle movements. The extended sensors allow transfer of data between roadside units or camera video improving the perception of the driving environment. Remote driving allows control of the vehicle remotely especially matching dangerous mission scenarios when people cannot drive by themselves. IEEE also has a similar standardization initiative in the name of "Dedicated Short Range Communications" (DSRC) using 802.11p assisting inter-device communication [9].

Integration with UAVs: Sidelink is envisioned to operate in A2A network segment wherein the devices in proximity can establish peer-to-peer transmission links for control and data exchange. Periodic information such as location updates, flight states can efficiently be shared within the UAV swarm for optimal mission-aware decision making and collision avoidance [10]. Hence, U2U communication offer high integration synergies with cellular sidelink feature.

Advantages and drawbacks: Application of sidelink to support A2A communication is significantly different from existing solutions for V2X communications. The primary challenge is due to the signal propagation environment, as well as the mobility. UAVs fly in 3D space with varying altitudes and the propagation medium suffers from additional attenuation and distortion effects. Secondly, UAVs are battery-constrained unlike terrestrial vehicles. Proper energy-aware path planning is essential for aerial missions encompassing UAVs.

E. Free Space Optical (FSO)

FSO and Visible Light Communication (VLC) are the two main candidates of optical wireless communications (OWC). FSO mainly refers to the use of outdoor/space laser links at the infrared band, while VLC relies on the use of light emitting diodes (LEDs) at the visible band mostly in indoor environments. VLC will be discussed in Section III-F.

Technology overview: FSO communications have been proposed as a promising technique to overcome the radio frequency (RF) drawbacks by providing high-speed transmissions in unregulated bands. License free spectrum, immunity to electromagnetic interference and inherent security are some notable advantages of FSO compared to conventional RF-based systems. FSO can efficiently establish high data rate point-to-point communication links, which can offer high bandwidth and ease the deployment efforts.

Standardization progress: Standardization efforts on OWC are still ongoing. At the international level, there are several large-scale projects on OWC technologies, such as (*i*) USA – LESA, UC-LIGHT, NASA-LCRD and COWA, (*ii*) Japan – VLCA and NICT space communication SOCRATES mission, and (*iii*) China - R&D for key VLC technologies. The ongoing VLC standardization efforts at IEEE and ITU (*e.g.* IEEE P802.15.13 and P802.11bb, and ITU-T G.vlc) further involve a number of international companies such as Intel, Huawei, LG, Cisco, Broadcom, and Nokia.

Integration with UAVs: The adoption of FSO for high data rate G2A and A2A links for airborne vehicles has recently attracted a great deal of attention *e.g.,* "Airborne Internet", relays. Besides A2A, FSO is seen to be useful for extending communication to space/ground networks [11]. In addition to the need for efficient pointing, acquisition and tracking

TABLE I: Technology highlights assisting drone networking in 6G vision.

Candidate Technology	Network Segment	Standardization Trends	Applications	Synergy between 6G and UAVs
Massive MIMO	Ground, G2A	Rel-13 & 14: beam-based NR with 16-32 antenna elements, Rel-15: 64+ antenna elements	Robust Surveillance & Centralized Info. dissemination	Enabler of Cellular-connected UAV swarm in 6G
mmWave	Ground, G2A, A2A	-	Flying Base stations, Relays	High throughput links for UAV-assisted cellular communication
Terahertz	Ground, G2A, A2A	IEEE 802.15.3d: 100G Wireless	Information Showers, Security-sensitive communications, Data center networking	HAPs and Space-to-Aerial data links, Short distance secure U2U links
Sidelink	Ground, A2A	Rel-12: D2D, Rel-13: UE-to-Network Relay, Rel-14: V2X, Rel-15: eV2X, IEEE 802.11p [9]	ProSe, V2X, Relay UE, C-U2X	Key enabler of U2U links in 6G
Free Space Optical	Ground, G2A, A2A, A2G	IEEE P802.15.13, P802.11bb, ITU-T G.vlc	Direct U2U communications, links from UAV to space or terrestrial networks	High data rate links between a ground station and UAVs, long distance end-to-end connections
Visible Light	Ground, A2A	JEITA CP-1221 (VLC system), and JEITA CP-1222, (VL ID system), ITU G.9991 IEEE 802.15.7	Indoor Localization, Indoor Communication, V2X	High synergy for U2U links in 6G

solutions, a better understanding of optical propagation is required for G2A links.

Advantages and drawbacks: FSO-based UAV communication is adversely impacted by weather interference and high UAV mobility. Harsh weather conditions lead to the signal loss and reduction of effective data rate. Besides atmospheric turbulence-induced fading, U2U links employing FSO are negatively affected by pointing error due to the position deviations of tall buildings. Distance longer than few kilometers affects FSO link reliability when incident beam is not always orthogonal in FSO-based UAV systems. To overcome such limitations, technical solutions attempt to mitigate the geometric and misalignment losses, considering the non-orthogonality of the laser beam and the random fluctuations of the position and orientation of the UAV. Finally, hybrid solutions based on the use of both RF and FSO are largely adopted for UAVs [12].

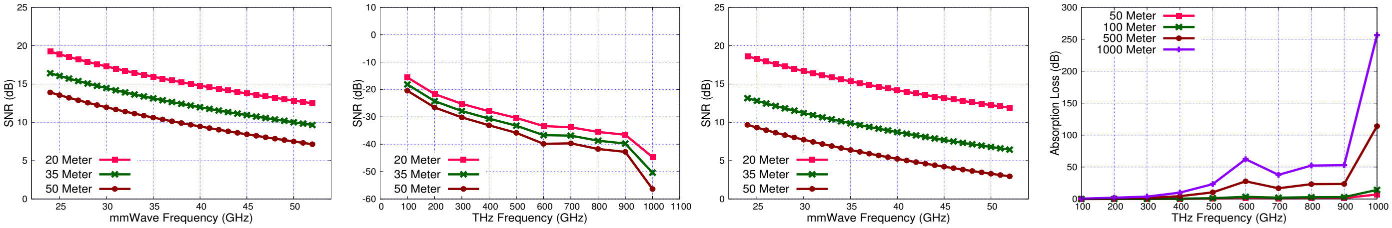
F. Visible Light Communication (VLC)

Technology overview: VLC has gained great interest in the last years, mainly due to the development of LEDs, as well as to its “green” feature. VLC mainly consists in the two-fold paradigm of both illumination and data communication, simultaneously by the same physical carrier. The fundamental components are: the transmitter (*e.g.* LED, camera), receiver (*e.g.* photodetector, camera) and the VLC channel. Besides LED, different light sources can be considered for transmitter. LED is an incoherent source, namely photons are emitted spontaneously with different uncorrelated phases. Photodetector as receivers in a VLC system, absorb the photons impinging on its frontend surface and generate an electrical signal. Channel modeling in VLC plays a crucial role for realizing effective, robust yet low complex systems. The easiest and most cost-effective modulation is based on Intensity Modulation/Direct Detection (IM/DD), which is not concerned by frequency and phase of the signal.

Standardization progress: Like FSO, the standardization progress related to VLC is still ongoing. The first standard for optical communication is IrDA, elaborated first time in 1993 for short range communication, but undergone several enhancements since then. In 2009, IEEE proposed the first standard for VLC *i.e.,* 802.15.7. The next versions of this standard include infra-red, ultraviolet, and optical camera communications (OCC). In 2018, a new working group for VLC, namely the IEEE 802.11bb, started activities for integrating the Li-Fi (Light-Fidelity) in order to make this technology interoperable with the Wi-Fi standard IEEE 802.11. This standard mainly focuses on MAC layer. Also, the IEEE 802.15.3 working group is considering OWC for wavelengths comprised between $10\mu m$ and $190nm$ with a bit rate of multi-Gbps. ITU is working on a standard for indoor optic communication, *i.e.*, the ITU-G99991.

Integration with UAVs: As demonstrated by the intense standardization activities, there have been significant advances on efficient physical layer design. One of the first contributions towards positioning the use of VLC for UAV networks is DroneVLC [13], where the VLC technology has been proposed as effective and robust communication technology among UAVs. However, many challenges still remain to be addressed for enabling VLC-based UAV networking, such as the need of LoS and occlusion robustness.

Advantages and Drawbacks: VLC exploits a portion of spectrum not used by other technologies. VLC is considered most effective in the absence of obstacles. The most important challenge while employing VLC for UAV communication is represented by a deep analysis of the specific characteristics of the channel and a precise channel modeling. Currently, VLC has been mostly applied for indoor applications. The presence of environmental source of interference (*e.g.,* sunlight), if not properly addressed, could prevent effective working of such a kind of technology. Moreover, it has been demonstrated that VLC is not completely immune to RF interference [14] and it needs to be carefully implemented in real environments (via realistic measurements) in order to exploit all its potential.



(a) mmWave G2A Propagation (b) THz G2A Propagation (c) mmWave A2A Propagation (d) THz A2A Absorption Loss

Fig. 3: SNR behavior for (a) mmWave G2A, (b) THz G2A and (c) mmWave A2A communication links. (d) Absorption loss for THz communication link.

IV. Discussions & Evaluations

All the technologies previously described are characterized with different features such as communication range, network topology, latency, data rates, mobility, etc. Each feature distinguishes different technologies according to their suitability for UAV communications and based on the specific type of mission/application they are devoted. Table I summarizes the candidate wireless technologies, by distinguishing where they can be applied with respect to the integrated space-air-ground communication network, and which applications they are reserved to. Also, in Table I we have collected the advances in the standardization progress, as well as the benefits carried out for UAV networking in 6G scenarios.

Although transmissions at higher frequencies offer immense benefits in terms of data rate, security, smaller size chips; it also faces significant impairments in propagation medium. In order to assess the propagation loss and signal-to-noise (SNR) ratio characteristics at higher frequencies for drone networking at different propagation distances (*i.e.*, 20, 35 and 50 meters), we perform four sets of experiments (implemented in MATLAB) encompassing (*i*) G2A using mmWave, (*ii*) A2A via mmWave, (*iii*) G2A using THz and (*iv*) A2A using THz. The results are shown in Fig. 3. The simulations parameters are summarized in Table II.

In our simulations, a statistical channel model urban macro (UMa-AV) scenario mentioned in 3GPP TR 36.777 is used, which characterize the G2A wireless channel between ground macro base station and drones using mmWave and THz band. The mmWave frequency is varied from 24 to 52 GHz range and THz frequency is varied from 100 to 1000 GHz range. The overall propagation loss in mmWave and THz band includes both spread loss and atmospheric absorption loss (according to Beer-Lambert law) where the molecular absorption coefficients are taken from the high-resolution transmission molecular absorption database (HITRAN) [15].

TABLE II: Simulation Parameters

Parameter	Value
Channel Model	3GPP TR 36.777
Scenario	UMa-AV (Urban Macro)
Base Station Height	25 Meters
UAV Height	50 Meters
Distance	$[20, 35, 50]$ Meters
Noise Figure	10 dB
Bandwidth (mmWave, THz)	(400 MHz, 50 GHz)
mmWave Freq. Range	$[24-52]$ GHz
THz Freq. Range	$[100-1000]$ GHz

We observe that irrespective of the type of the link, the SNR decreases at higher frequencies for a fixed receiver distance and also decreases for far-away receivers at a fixed frequency. For the G2A link, the SNR gap is nearly 63 dB between a carrier at 50 GHz (mmWave) and 1000 GHz (THz). The harsh propagation environment at higher frequencies necessitates adoption of highly directional antennas and beamforming gains, more antenna elements to compensate the loss. THz has smaller wavelengths that translates to narrower beams and large of THz antennas can be fit into very small area, thus making the transceivers compact. As shown in Fig. 3c, SNR at mmWave frequencies for the A2A links (*i.e.*, 2.96 dB at 52 GHz) drops at higher rate than G2A links (*i.e.*, 7.14 dB at 52 GHz) for far-way distances (*i.e.*, 50 m). The atmospheric absorption loss in higher frequencies for LAPs (close to sea-level) are shown in Fig. 3d. Clearly, higher atmospheric absorption losses when the transmitter and receiver distance increases makes it very challenging for the LAPs to establish efficient transmission links.

Finally, a few considerations about the next steps into the drone standardization process. The ambitious applications and use-cases involving UAVs have attracted standardization bodies to develop standards promoting smooth integration of drone technologies to wireless networks. These standards assist as an integrative mechanism for industry partners and researchers to harmonize their respective developments. Fig. 4 presents an overview of standardization items concerning drone networking by three major standard governing bodies, *i.e.* 3GPP, IEEE and ITU.

V. Concluding Remarks

Mutual synergies of UAVs integrated with 6G systems may offer a cost-effective ecosystem and unlock several emerging use cases. High date rates, very low latency, global coverage, and programmability are expected in next generation networks. However, as several innovative convergence technologies for drone networks in 6G continue to sprout up, more promising discussions are needed on how these candidate technologies unify in futuristic 6G vision. We believe this work will serve as a basis for exploring unique innovations and moving towards establishing a road map for UAVs in 6G futuristic network.

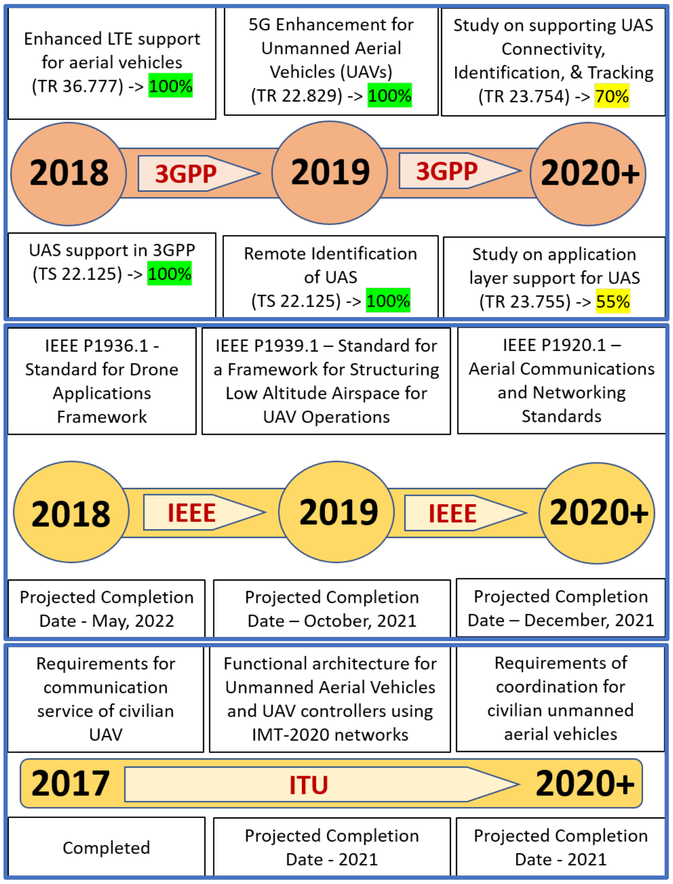


Fig. 4: Scheduled standardization items concerning UAVs.

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