Is 5G Ready for Drones: A Look into Contemporary and Prospective Wireless Networks from a Standardization Perspective

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***Abstract*—There are two main questions regarding the interaction of drones with wireless networks: First, how wireless networks can support personal or professional use of drones. Second, how drones can support the wireless network performance, i.e, boosting capacity on-demand, increasing coverage range, enhancing reliability and agility as an aerial node. From a communications perspective, this article categorizes drones of the first case as mobile-enabled drones (MEDs), and drones of the second case as wireless infrastructure drones (WIDs). At the dawn of 5G Phase-I completion (Rel-15), this study investigates both the MED and WID cases within the realistic constraints of 5G. Furthermore, we discuss potential solutions for highlighted open issues, either via application of current standards, or by providing suggestions towards further enhancements. Although integrating drones into cellular networks is a rather complicated issue, 4G LTE-A and the 5G Rel-15 standards seem to have significant accomplishments in building fundamental mechanisms. Nevertheless, fine tuning future releases by studying existing methods from the aspects of MEDs and WIDs, and bridging the gaps with new techniques is still needed.**

I. Introduction

Numerous civil applications of drones across industries as well as their invasion of the market of consumer electronics have led to an increasing demand for providing wireless connectivity to drones. Mobile networks are most suitable to provide reliable and secure wide-area connectivity to drones [1]. Meanwhile, the need for ubiquitous connectivity for a diverse range of user equipments (UEs) including driverless cars, sensors, and enhanced mobile broadband (eMBB) devices, drew attention to airborne communications. Various types of aerial-nodes have shown to be promising in improving performance, agility and flexibility of 5G and beyond mobile networks in unprecedented manners [2]–[9].

From a communications perspective, this article categorizes drones enhanced by mobile networks as mobile-enabled drones (MEDs), and aerial-nodes supporting wireless networks as wireless infrastructure drones (WIDs). In both categories, unless otherwise stated, e.g., high-altitude platforms, the preferred type of drones is similar to medium-sized devices with moderate capabilities, e.g., quadrators or fixed-wing unmanned airplanes [2], [7]. Note that WIDs are a subset of networked flying platforms, where the term also covers non-terrestrial networks[1] (NTNs) (TR 38.811).

or discussing the communication aspects of MEDs and WIDs, this article has two aims: First, highlighting crucial information about 3GPP standardization which serves as a basis for research on the integration of drones into contemporary and prospective mobile networks. Second, discussing solutions for open issues, either via applications of current methods, or by providing suggestions towards further enhancements. Throughout this article, we help interested researchers navigate the standardization documents by pointing relevant references. In particular, one of the aims of this study is to serve as a bridge between the researchers in academia and industry by presenting a comprehensive discussion of the current trends in 5G standardization activities. To the best of our knowledge, this is the first work in the literature which covers the integration of drones from both the radio access network (RAN) and fundamental system architecture (SA) aspects at the same time.

II. Drones and Mobile Networks

Drones have diverse capabilities and scales from nano-robots to aircrafts with larger wingspans than a Boeing [2]. That variety reflects in terminology by creating a number of terms such as Unmanned Aerial Vehicles or Systems (UAV or UAS, respectively). Compared to the other terms,“drone" is a vague one; it means a remotely controlled device which can operate in any medium (air, water, or land). However, “drone” is also the most popular and compact term. Thus, it is endorsed in this article. There are ongoing standardization activities in 3GPP for providing enhanced wireless connectivity to personal and commercial drones via mobile networks, i.e., MEDs or aerial-UEs (AUEs). However, enhancing mobile networks via utilization of drones providing direct or indirect connectivity to other UEs, i.e., WIDs, is a fairly new scenario. Note that the same equipment may be utilized both as a MED and as a WID. In this case, MED and WID correspond to different operational modes, rather than devices.

A. Mobile-Enabled Drones

Drones in this category are UEs from the perspective of wireless networks, i.e., a business client, which may also

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[1]“Networked flying platform,” Mar 2018, Accessed: 2018-04-28. [Online]. Available: https://en.wikipedia.org/wiki/Networked_flying_platform.

include private drone networks. Currently, drones are being used in vast applications, including inspections and surveys, transport and logistics, and surveillance and monitoring. In TR 36.777[2] a maximum altitude of 300 m and a maximum speed of 160 km/h is determined for both rural and urban scenarios of such drones. These use cases should not be confused with the "commercial air-to-ground" in TR 38.913, where the term means providing mobile connectivity services to humans and machines on-board commercial aircrafts.

Traditionally, drones use unlicensed links to communicate with a ground control station (GCS), or drone pilots [10]. However, unlicensed links have limited reliability and range due to the propagation impairments of remote control signals in beyond-visual-LOS (BVLOS) operations, which are mostly prohibited, which are mostly prohibited, e.g., in USA by the Federal Aviation Administration. Contrarily, mobile networks can enable BVLOS operations thanks to their wide coverage and reliability. Moreover, secure communications (TS 33.501), capability for lawful intercept (TS 33.107), location verification, and trusted identification (TR 33.899) are side benefits that can be obtained via current and next-generations of standardized mobile networks [1].

MEDs establish two types of links with a GCS: First, the command&control link is used for remote piloting, telemetry data, identity, navigation, and similar (TR 36.777). Although telecommand and telemetry links come under a single non-payload communications umbrella, remote piloting may require video transmission to provide a near-there feeling to the pilot. Since many regulatory bodies do not approve fully autonomous drones (due to operational risks), and drones can operate only in semi-automated fashion under the supervision of drone pilots, command&control links are critical [10]. Second type of link established with a GCS is the application link that delivers information, such as sensor data, video, audio, and images. Note that the application link mostly requires payload communication capabilities. On the other hand, application data is less critical than command&control for many cases. Therefore, both throughput and reliability requirements vary (Table I).

B. Wireless Infrastructure Drones

Differently from MEDs, WIDs serve to enhance network capabilities, e.g., by increasing coverage or capacity. WIDs can be classified based on their functionalities and requirements:

1) Aerial- or Drone-BSs: Drone-BSs serve as aerial-nodes with some or all functionalities of BSs, (e.g., an aerial-eNB, or an aerial distributed unit (DU)) creating drone-cells [2]. For drone-BSs, both wireless backhaul and fronthaul may be required [9], or either one of them may be provided via tethering. Downlink and/or uplink radio access can be licensed or unlicensed. Drone-BSs have various moving patterns, e.g., hovering, rotating, floating, following a specific route, or landing on suitable locations (e.g., top of buildings). These patterns depend on environmental conditions, machinery, and communication requirements.

2) Aerial-relays (AR): ARs can be deployed by users or operators. In the former case, unlicensed spectrum can be used for the links between user and AR, and the AR acts as a UE for the mobile networks. Operator-deployed ARs can be more sophisticated, and should be integrated appropriately. They can act as intermediate hops for integrated access and backhaul (IAB) (Sec. III-B3), or simple analog repeater with up/down converters.

3) Aerial backhaul/fronthaul providers: Drones form NTNs providing an aerial transport network (ATN). The interest in ATNs is rapidly increasing[4]. While both licensed and unlicensed solutions are possible, the hybrid ones seem the most efficient. TR 38.811 considers satellites as part of the NTN of 5G networks. However, they are not considered here, as the altitude is above the limits within which small cell/relay-like operations are feasible.

III. Progress of 5G Standardization and what it means for drones

In this section, selected capabilities of 5G networks are discussed based on Rel-15[5] developments in RAN (RAN1, RAN2, RAN3) and SA working groups (SA2, SA5). This section is organized as follows: First, the concept of slicing is explained. Then, 5G RAN topics which are primarily important are investigated. These topics include standardization activities for MEDs, architectural roles for MEDs and WIDs, integrated access and backhaul studies, and licensed/unlicensed options from the perspective of drones. Finally, 5G core and 5G network management studies are discussed in terms of solutions they can promise for the integration of drones.

A. Slicing

Slicing enables service-oriented configuration of wireless networks in a flexible and agile manner [11]. Hence, the network is arranged to support different drone services, e.g., a slice configured for application links of MEDs, or a slice to isolate the traffic of WIDs. (Fig. 1(a)).

For SA2 and RAN, slice is a "logical network that provides specific network capabilities and network characteristics". However, SA5 considers "managed network slice instances" (NSIs) with various constituents, i.e., managed network slice-subnet instances (NSSIs), e.g., with respect to domain (RAN, core), or location (Ottawa, Toronto, etc.). Fig. 1(b) shows two 5G-core slices isolating the traffic and network resources of a WID and gNB. Note that slices have shared (e.g., AMF, SMF) and non-shared components (e.g., user-plane functions, NEF). From a management perspective, 5G-core slices are each an NSSI, where an end-to-end NSI contains RAN-NSSI and CN-NSSI (Sec. III-D) (Fig. 1(a)).

[2]All TR and TS documents are 3GPP technical report and specification documents, respectively. The acronym of "3GPP" is omitted for brevity.

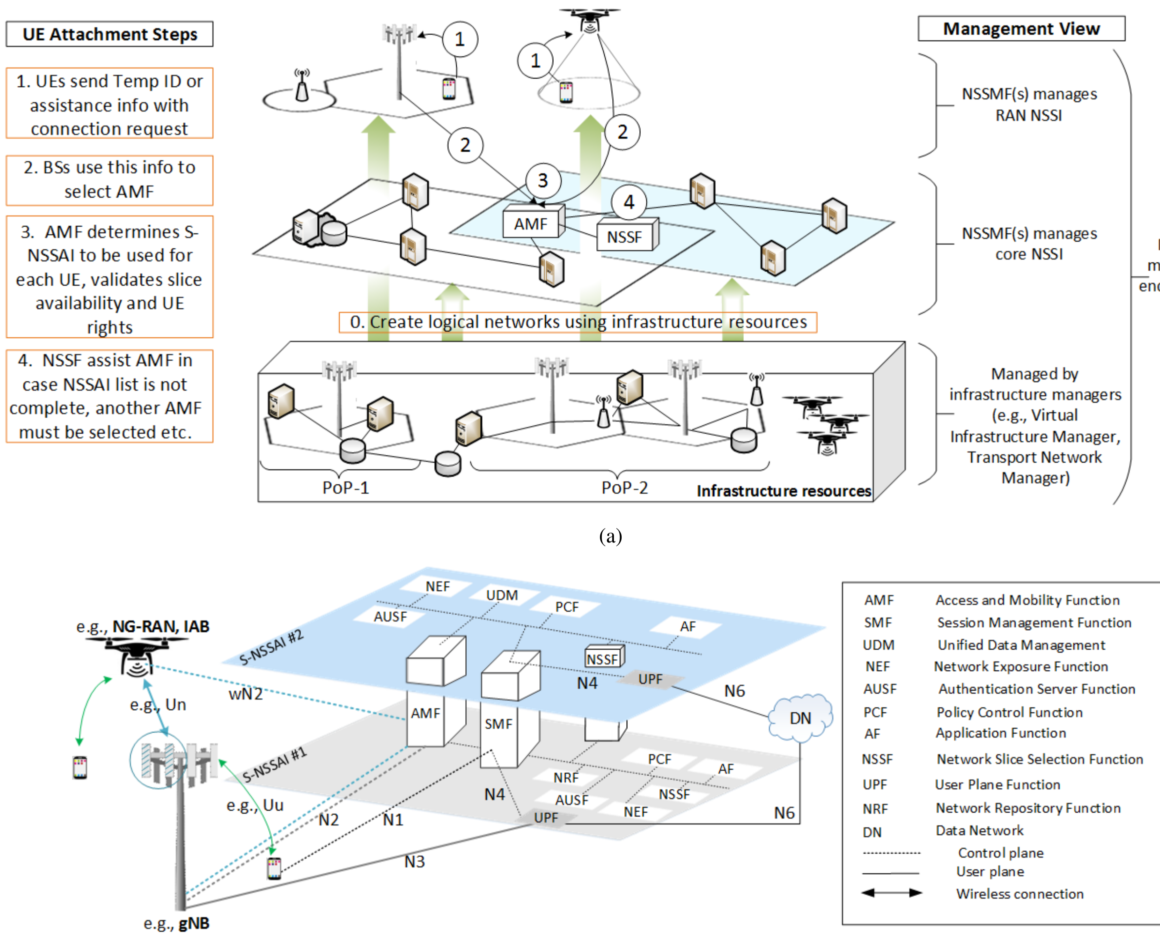
[3]For 1 GHz bandwidth at 26 GHz band.

[4]"FCC authorizes SpaceX to provide broadband satellite services," Mar 2018, Accessed: 2018-04-04. [Online]. Available: https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0329/DOC-349998A1.pdf.

[5]All releases in this article are 3GPP releases, however, the acronym of "3GPP" is omitted for brevity.

TABLE I: QoS requirements for URLLC, eMBB and MED scenarios in 3GPP RAN documents (“uns” indicates unspecified field)

QoS requirements	URLLC	eMBB	MED Command&Control	MED Application
User Plane Latency (UL/DL)	0.5ms / 0.5 ms	4 ms / 4 ms	50 ms / uns.	50-400 ms
Reliability (1-Block Error Rate)	$1 \quad 10^{5}$	$1 \quad 10^{3}$	$1 \quad 10^{3}$	uns.
Peak Data Rate (UL/DL)	1.75 Gbps / 6.5-13 Gbps^{3}	1.75 Gbps / 6.5-13 Gbps	60-100 kbps	50 Mbps



(a)

(b)

Fig. 1: Wireless networks with slicing and integration of WIDs: (a) Creation of logical networks from infrastructure pools. Some initial UE-attachment steps are highlighted. (b) Interfaces and service-based 5G-core slices. A WID-specific 5G-core slice may include common and non-shared NFs; the upper WID slice has isolated resources from the gNB slice below. Circle depicts gNB resources reserved to provide backhaul and/or fronthaul to the WID (hard-slicing in RAN).

B. 5G RAN

RAN supports slicing extensively, e.g., by allowing hard slicing and resource isolation between slices, QoS differentiation within a slice, and awareness of slice identification. Some further developments in RAN and their meaning for drones are discussed next.

1) Standardization for MEDs: The most comprehensive study for MEDs is in TR 36.777 where definitions, scenarios, performance requirements and metrics, interference problem and potential remedies are discussed. Data and setups regarding field trial results, system-level and mobility evaluations, and fast fading models are going to be provided in future versions.

Performance metrics in TR 36.777 are presented in Table I in comparison to QoS requirements of URLLC and eMBB cases (TR 38.918). Table I shows that MEDs require 100 times less reliability than URLLC, and 200 times less peak data rate than eMBB.

Mostly RAN working groups perform standardization activities regarding MEDs, whereas SA2/5 has no specific study for MEDs. Although MEDs are considered among IoT, URLLC and eMBB scenarios (TS 23.501, Sec. III-C), considering Table I, such categorization may be imprecise.

2) Architectural Roles: 5G architecture benefits from decoupling roles, capabilities, and functionalities of network elements to provide flexible and diverse technical solutions that can be tailored for specific needs. Hence, there are various integration options for WIDs with varying levels of flexibility, cost, security, and complexity.

There are 3 types[6] of RAN nodes in Rel-15:

eNB: E-UTRA user-plane and control-plane protocol termination towards UE, connected to EPC core via S1 interface (TS 36.300)

ng-eNB: E-UTRA user-plane and control-plane protocol termination towards UE, connected to 5G-core via NG interface (TS 38.300).

gNB: New radio (NR) user-plane and control-plane protocol termination towards UE, connected to 5G-core via NG interface (TS 38.300).

Also, NG-RAN node refers to gNB or ng-eNB. Until full-fledged 5G is deployed, and 5G UEs become widely available, inter-working between 4G and 5G is necessary to provide seamless service. Inter-working can be in standalone or non-standalone mode. If non-standalone, a WID acts as an *aerial-NR node* providing high data rate user-plane communications to the UE, while control-plane is handled by the terrestrial-eNB. Note that the NR node is only connected to eNB and service-gateway or user-plane functions in this case (Fig. 2(a) and Fig. 2(b), Sec. III-B4). If standalone, WIDs can be ng-eNBs or gNBs with wireless backhaul (Fig. 3) while UEs that are compatible with LTE/LTE-A and 5G can access either one of the cells [12].

BSs can be deployed with hierarchy as master and secondary nodes, in case of Multi-RAT dual connectivity (DC) (TS 36.340). Either ng-eNB or gNB can be the master node of the other, known as NGEN-DC or NE-DC, respectively (TS 37.340). Similarly, EN-DC indicates that an eNB is the master node of an NG-RAN node. Although, in principle, all DC options can be viable for WIDs (Fig. 2(a) and Fig. 2(b)), it is more efficient for WIDs to be secondary nodes to reduce complexity, and prevent excess control-plane latency due to wireless fronthaul/backhaul.

Accordingly, WIDs can be aerial-DUs with limited functionalities of a central unit (CU) (Fig. 3). The CU/DU split is proposed to enable and enhance the cloud-RAN technology via several split options (TR 38.801) that allow arranging centralization vs distribution of control and capabilities depending on each situation of wireless networks, e.g., supporting large number of UEs, abundance or scarcity of bandwidth, delay tolerant or sensitive applications, and expanding coverage range.

Out of 8 split options, option-2 and option-3 are mostly debated (Fig. 11.1.1-1, TR 38.801). In option-2, radio link control (RLC) is with DU, and packet data convergence protocol (PDCP) is with CU; radio resource control protocols for signaling radio bearers and service data adaptation protocol (SDAP) for data radio bearers are also with CU (TS 38.401). There is no split for signaling radio bearers, if option-2.1 is used (3C-like split); wherein DUs need to have all layers and required capabilities of control-plane. In option-3, both signaling and data radio bearers are divided at the RLC level, where high-RLC is with CU and low-RLC is with DU. Option-3 thus enables lighter DUs compared to option-2. However, option-3 wastes fronthaul bandwidth for radio resource control and management protocols, as observed from procedures in TS 38.401.

RAN1 studies lower-layer-split options in TR 38.816. Based on calculations with parameter sets including uplink/downlink channel bandwidth, modulation scheme, and number of antenna ports, Option-6 and Option-7.1 require 4.1 to 18.2 Gbps, and 37.6 to 454.6 Gbps fronthaul rate for downlink, respectively. Despite the large variation of required fronthaul rate, note that achieving high rates between aerial-DUs and CUs are possible thanks to LOS opportunities, and wide spectrum in NR.

There are multiple trade-offs when split options are considered for WIDs. First, lower-layer-split increases bandwidth requirement and decreases tolerance to latency for the fronthaul link, compared to upper layer splits. It also increases the complexity to transmit the signal over the fronthaul (especially for PHY layer). Nonetheless, lower-layer-split reduces computational requirements of DU significantly. That can increase airtime, if fronthaul links with high-SINR and large bandwidth are available. Finally, lower-layer-split makes centralization more effective, and increases the number of UEs that can be served by the DU.

3) Integrated Access and Backhaul: Recently, RAN working groups approved study items for IAB to support wireless network densification without scaling transport network. Importance of IAB for WIDs is twofold: First, an aerial-relay can utilize wireless backhauling that is natively supported by 5G networks. Second, a WID as an intermediate IAB-node can reduce number of hops, and provide topology flexibility thanks to LOS and mobility.

Omitting visible-light communications, TR 38.874 considers carrier frequencies up to 100 GHz. However, above-6 GHz frequencies pose challenges due to short-range, and interruptibility of links. WIDs[7] can provide efficient solutions due to mobility, which relaxes frequent switching, and multi-connectivity requirements [13]. Also, WIDs' mobility enables flexibility in topology design, and alleviates the problem of coverage holes by following the crowd at the cell-edge. Since LOS is likely, subtle enhancements in PHY layer may suffice. However, the limiting factor, especially for in-band backhauling, is co-channel interference [9]. Re-visiting L2/L3-relay architectures, and investigating their trade-offs in drone-IAB context can reveal practical solutions, e.g., utilizing RLC-based relaying with an adaptation layer carrying routing address, drone's coordinates, and QoS related information [13].

4) Licensed/Unlicensed options for MEDs and WIDs: Given the specifications of licensed-assisted access (LAA) to unlicensed spectrum (Rel-13 TS 36.213 to Rel-15 TS 37.213), an interesting question arises: Can drones benefit from LAA? Since only small cells can exploit such mechanisms due to the maximum transmit power regulations, the answer actually

[6]There is also en-gNB, with NR user-plane and control-plane protocol termination towards UE, connected to EPC core via S1 interface. Although en-gNB seems to be a natural evolutionary step, it is not standardized by 3GPP.

[7]Although Rel-15 considers fixed relays, it does not preclude optimization for mobile relays in future releases.

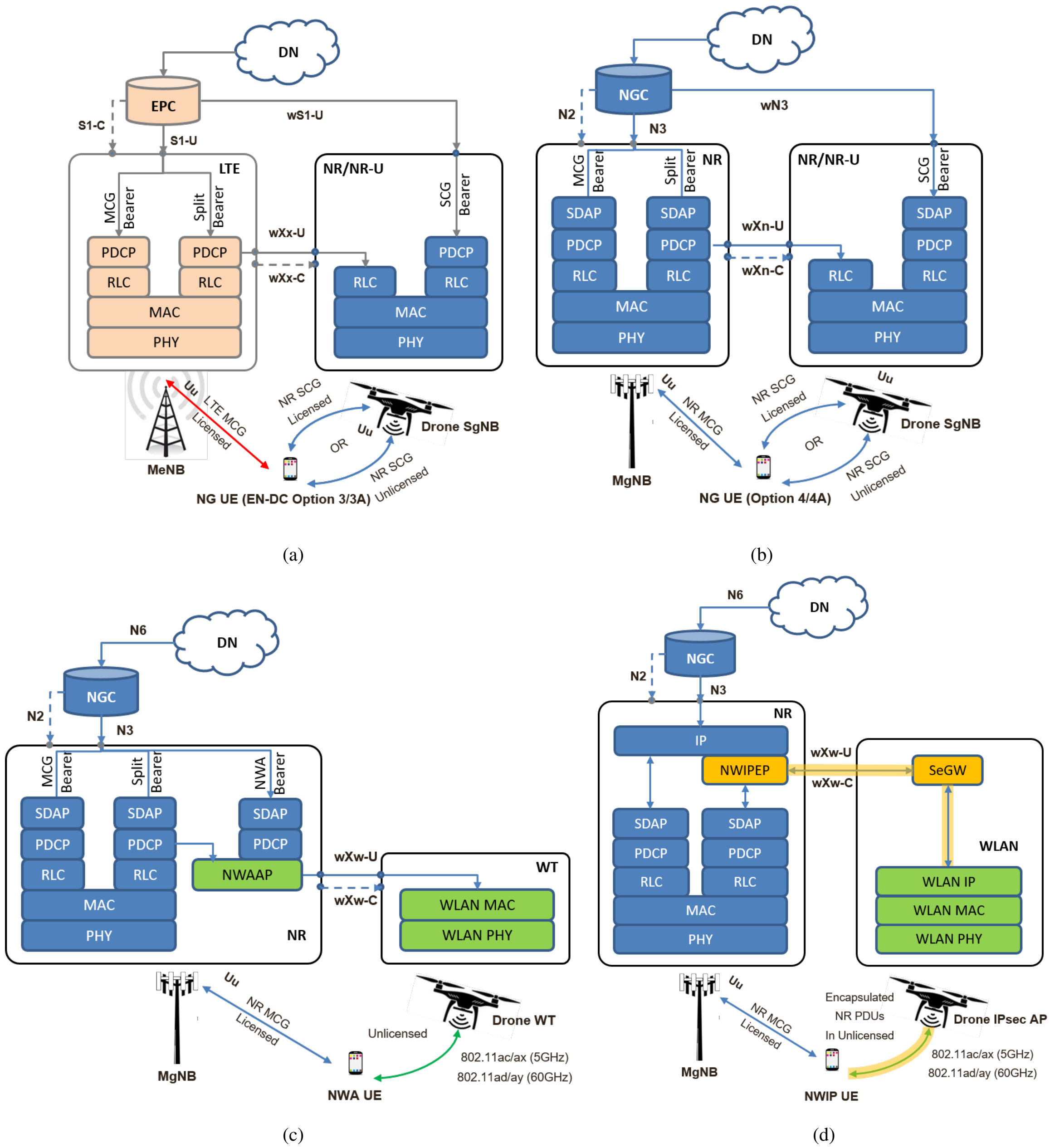


Fig. 2: Combined protocol stack architecture and simplified reference point model for different licensed/unlicensed WID integration options: (a) Drone-SgNB using NR/NR-U radio in EN-DC option 3/3A; (b) Drone-SgNB using NR/NR-U radio in NE-DC option 4/4A; (c) WLAN termination drone in NR-WLAN aggregation; (d) Drone IPsec Access Point in NR-WLAN integration using IPsec tunnel.

depends on the envisioned range and altitude of the drone application compared to the coverage of these LAA cells, which may not extend beyond 150 m. In Rel-15, a study item on NR-based access to unlicensed spectrum (NR-U) (Fig. 5) was approved with the objective of porting the NR enhancements, such as the flexible numerology (sub-carrier spacing), mini-slot, frame structure, and wideband operations, to the unlicensed spectrum either below or above 7 GHz (TS 38.889). Employing larger sub-carrier spacing and/or mini-slot based transmissions increases throughput, but renders less energy per symbol for the same transmit power, and hence, reduced coverage. Consequently, it is more difficult to support the access links of some drone applications.

While mmWave and beamforming techniques of NR can enhance the received SINR at drones via narrow beams and interference suppression, they may not enhance the received signal power in the unlicensed band as a transmit power backoff would be necessary to comply with the maximum EIRP[8] regulations. This in fact suggests that a 5G NR-U air interface, may not be suitable for the radio access links of NR-U MEDs as they would have to maintain close proximity

[8]EIRP stands for equivalent isotropic radiated power.

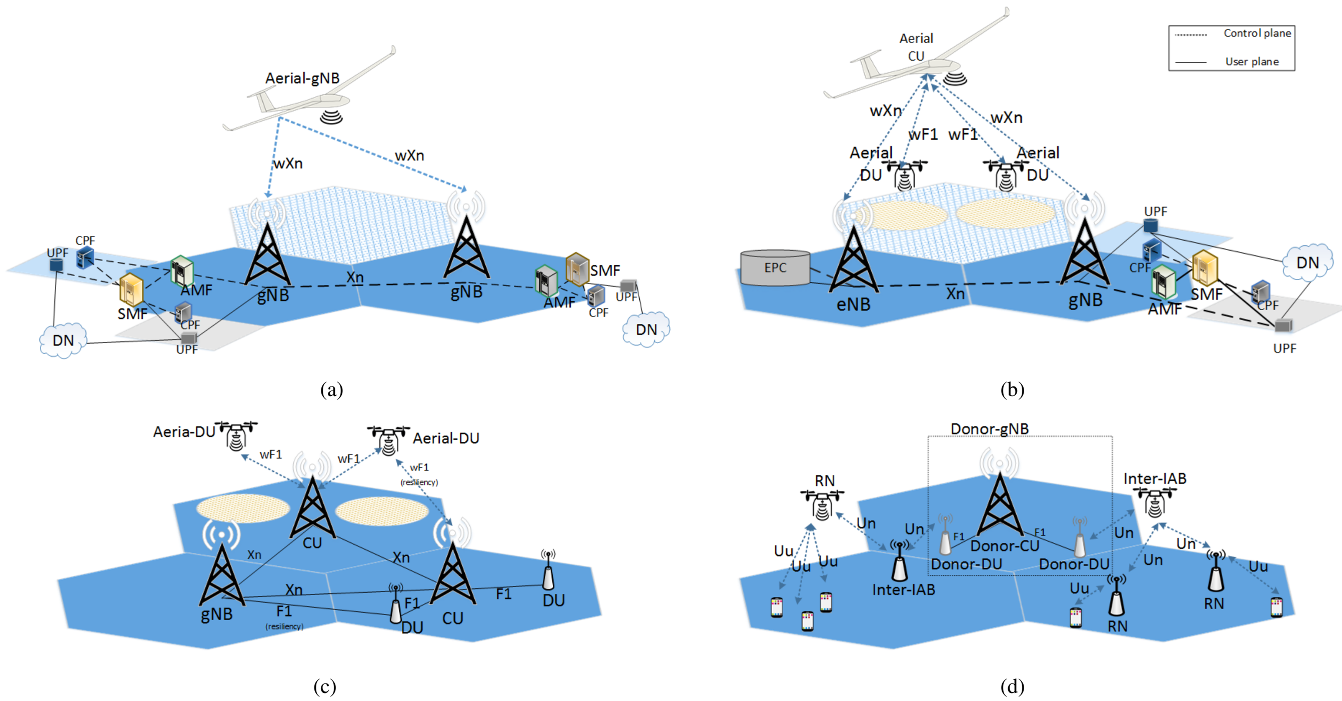


Fig. 3: Some architecture options for WIDs where interfaces with potential enhancements are marked with "w": (a) A standalone aerial-gNB with a specific 5G-core-slice for WID-originated traffic (blue slice); (b) A fleet of WIDs with aerial-DUs and an aerial-CU with a specific 5G-core-slice for WID-originated traffic (blue slice); (c) Aerial-DUs associated with terrestrial-CUs (no specific 5G-core-slice for WID-originated traffic); (d) WIDs as relay nodes and intermediate IAB nodes. There are at least protocol stack differences between the two types of nodes.

to the serving micro/pico cells. Contrarily, it can be suitable for the radio access links of NR-U UEs served by non-standalone WIDs. In Fig. 2(a) and Fig. 2(b) the serving drone-secondary-gNB (drone-SgNB) can maintain close proximity to the DC UEs while its user-plane/control-plane connections are provided over the licensed band within the large coverage of a Macro Master-eNB (MeNB) or Master-gNB (MgNB), respectively.

The operation of the UEs in Fig. 2(a) should be supported by the specified EN-DC options-3/3A where a wireless Xx-C connection to the MeNB carries the control-plane data. First, a wireless Xx-U connection carries the user-plane data through the LTE PDCP layer to the NR RLC layer of the drone-SgNB, if a split bearer between the MeNB and the drone-SgNB (option-3) is utilized. Second, when EPC switches to a secondary cell group (SCG) bearer (option-3A), wireless S1-U connection to the EPC carries the user-plane data directly through the NR PDCP layer of the drone-SgNB. These two cases are indeed of particular importance since they are likely to resemble the early stage of migration from LTE to 5G. Similarly, operations of UEs in Fig. 2(b) should be supported by specified full-5G options-4/4A where a wireless Xn-C connection to the Master-gNB carries the control-plane data. In case of a split bearer between the Master-gNB and the drone-SgNB (option-4), a wireless Xn-U connection carries the user-plane data through the NR SDAP that is required for mapping bearer packets to QoS classes before the PDCP layer. Whereas in case of a (switched) SCG bearer (option-4A), a wireless N3 connection to the 5G-core carries the user-plane data directly through the NR SDAP sublayer of the drone-SgNB.

Mobile network access to the unlicensed spectrum, either through LTE LAA or 5G NR-U, could have been designed to fulfill only the regulatory requirements. However, a fair coexistence with incumbent RATs such as WiFi would not be guaranteed. Due to their inherent fairness to WiFi, older technologies specified before LAA for LTE to exploit the unlicensed spectrum through Carrier WiFi offloading are still credible technologies, and thus expected to be adopted in 5G networks as shown in Fig. 2(c) and Fig. 2(d). One solution thereof is aggregation of NR and WLAN at the PDCP-level (NWA). In such case, only a non-collocated implementation is feasible for a drone-WLAN termination. This is obviously the simplest and most cost-efficient integration scenario of WIDs for unlicensed access. The other solution is IP-level integration of NR and WLAN (NWIP) wherein UEs operate in multi-homing mode and handle two different IP flows over the two air interfaces. However, the IP flow offloaded to the drone-AP is relatively unsecured and an IPsec tunnel is therefore established between the Master-gNB and the UE through the drone-AP by encapsulating the NR PDUs using an NWIPEP sublayer.

As described, despite its limitations for MEDs especially above 7 GHz, NR-Unlicensed as well as the NR-WLAN aggregation/integration options provide multifarious integration options for WIDs while exploiting the vast and free-of-charge unlicensed spectrum. Further studies should investigate the efficiency of these options by considering multitude scenarios from dense deployments to IoT and URLLC.

C. 5G Core

In order to better exploit advantages of NFV and SDN, enable automation, and improve flexibility, 5G-core networks established a service-based architecture (Fig. 1(b)). Principles of the 5G-core architecture design includes allowing a NF to talk to other NFs directly, supporting multi-vendor integration, and allowing different slices with unique configurations (TS 23.501).

Service-based 5G-core enhances existing functions by dissecting their functionalities into new functions. For instance, the mobility and management entity (MME) of EPC is dissected into AMF and SMF (Fig. 1(b)). AMF is the termination of non-access stratum, and includes functionalities such as mobility management, access authentication, and lawful intercept (TS 23.501). Similarly, SMF has roaming functionality of MME, and also control-plane functionalities of Service- and packet-gateways, such as UE IP address allocation and management. Most control-plane NFs are enhanced with slice-awareness, e.g., AMF selects network slice during attachment of UEs (TS 38.801, Fig. 1(a)). Single network slice selection assistance information (S-NSSAI) identifies a network slice. An S-NSSAI consists of a slice/service type (SST) referring to main characteristics of NS, e.g., eMBB, uRLLC, and a slice differentiator (SD) that differentiates the slice within the same SST optionally.

Increased support for virtualization and slicing at core makes it easier to integrate new functions, specifically supporting MEDs and WIDs [2]. However, there are many issues on how to use this flexibility. Since MED traffic varies from latency-tolerant telemetry data, to bandwidth hungry live video streaming, MEDs may be associated with multiple slices. A UE can be associated with 8 slice instances simultaneously, and whether it is enough for MEDs or not depends on the application, and design of the slices. TS 23.401 recently included subscription support for high-level aerial-UE functions, and how they are transmitted in the EPC during handover. However, slicing aspects of MED support, e.g., a specific SST or SD value, is missing. Network exposure function (NEF) allows exposure of control-plane NF capabilities in a controlled fashion to external entities, e.g., untrusted application function, edge computing, and other vendor's control-plane NFs. NEF can make deploying edge computing to support MED operations[9], more economic and faster.

Regarding WIDs, a key issue is carrying their traffic without impacting the existing services. One way is to create a slice for a WID, potentially with some shared control-plane NFs and non-shared user-plane functions. However, creating only one slice may not be enough, since there may be UEs with different services. Then, many trade-offs appear in this scenario: Since drone-BS operations are expensive, the objective is to utilize drone-BS for as many services as possible. Therefore, multiple 5G-core slices may need to be created for each WID. That is costly, hard to manage, and increases the burden on wireless interfaces for updates regarding NSSAIs, e.g., N2 and N1. If existing slices are shared, providing sufficient isolation is challenging; monitoring traffic of many services require high-level of granularity. Complexity increases exponentially for integration of drone fleets, which necessitates efficient management systems.

[9]"Hangar and Vapor IO to deliver autonomous robotics at the kinetic edge," Mar 2018, Accessed: 2018-04-04. [Online]. Available: https://www.vapor.io/hangar-and-vapor-to-deliver-autonomous-robotics-at-the-kinetic-edge/.

D. 5G Network Management

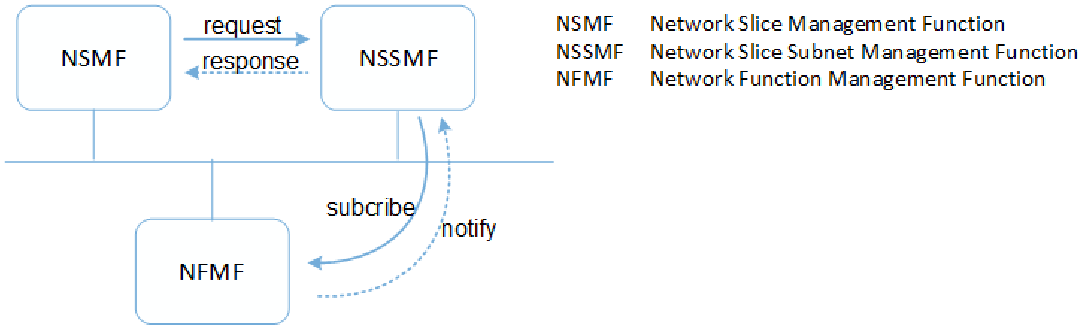
Network management is traditionally responsible for FCAPS, i.e., Fault, Charging, Authorization, Performance, and Security management. Recently, challenging management requirements of flexible networks lead to new management functions, and a service-based management and orchestration system. NSI, NSSI, and NF Management Service Functions (NSMF, NSSMF, and NFMF, respectively) consist of other services, e.g., performance management (PM). In this architecture, a management service provider and its consumer can have various relationships as shown in Fig. 4(a).

Accordingly, drones can be managed by various management entities, depending on the drone's role. Fig. 4(b) show an example slice provisioning procedure, where drones are shown as a slice consumer, as well as NSSI, NF, and infrastructure providers. In fact, TS 28.530 supports Network-slice-as-a-Service (NSaaS), which may be delivered with different information and management exposure. However, NF and infrastructure providers are not explicitly supported by current standards.

In the presence of various business options, and a layered network with constituents at different levels, integrating WIDs may require updating TSs. For instance, new network resource model entities, similar to the additions in TS 28.541 for CU/DU, may be useful. Moreover, FCAPS requirements for WIDs are not yet investigated in detail. For instance, how to configure a WID to measure and report load information? Are there additional alarms that should be raised by WIDs or MEDs, e.g., remaining fuel, malfunction? Moreover, there are proposals to turn network management systems into the core of the network automation and optimization with end-to-end data collection and analysis capability [14]. That makes network management critical in drone integration as the provider of information to make decisions, e.g., determining role of WIDs. However, these automation mechanisms are not yet in the standards, and there is no consensus on distribution of responsibilities, e.g., between SA2 and SA5. In fact, solutions to these issues can only be obtained by clear descriptions of roles of WIDs in 3GPP networks, and coordination among standardization organizations and working groups. Issues requiring more than coordination but substantial research are discussed next.

IV. Future of Standardization and Research Directions

In Fig. 5 completion percentage of study items in Rel-15 that are related to the aspects discussed so far are shown.



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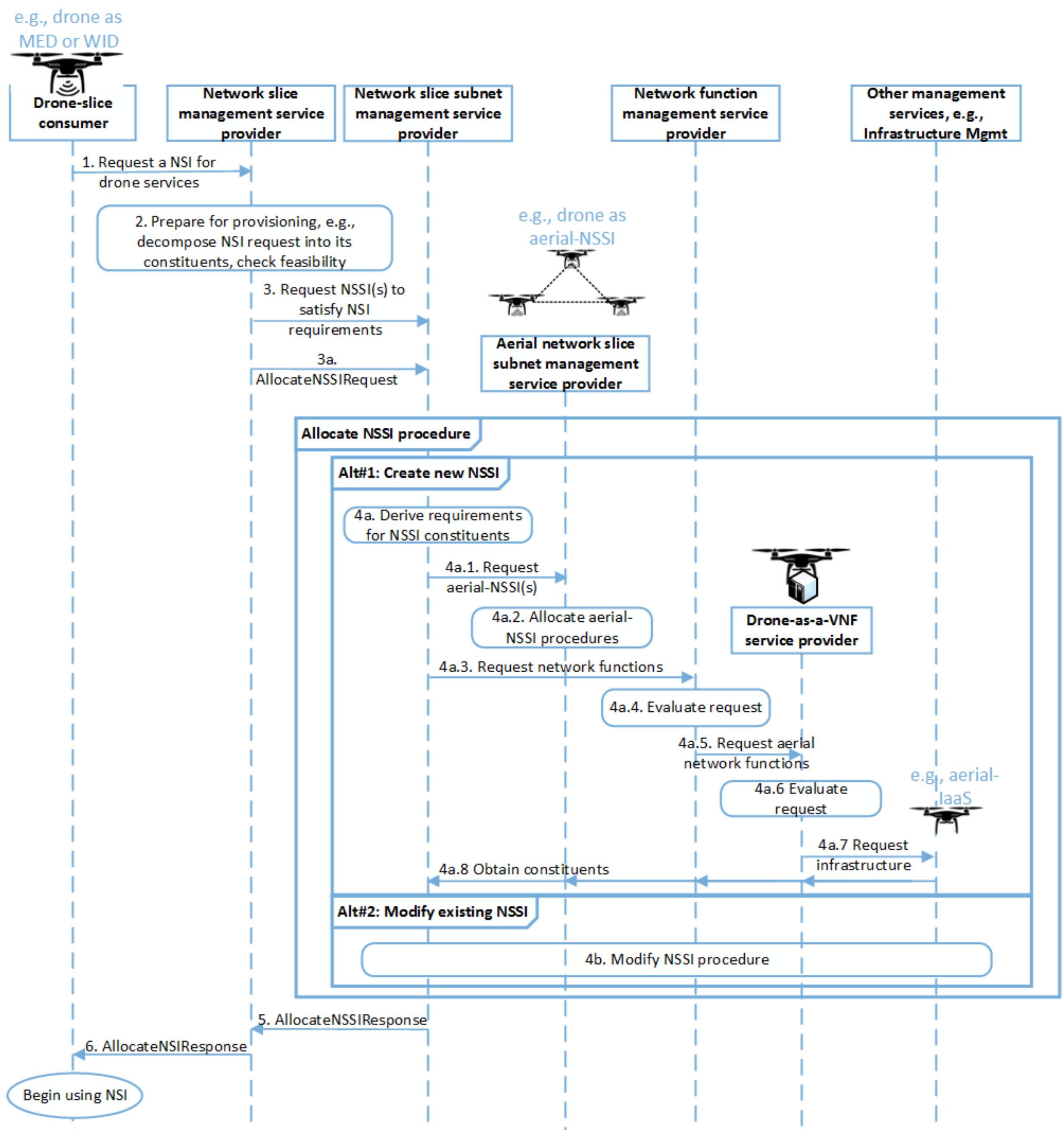

(b)

Fig. 4: Network management system overview: (a) SBA allows any network management service provider to access another via "request-response" or "subscribe-notify" messages; (b) Overview of network slice provisioning procedures: An NSI request may be responded via creation of a new slice or modification of an existing one. Provisioning requests are decomposed into their constituents by corresponding management service providers. Drones can have varying roles in mobile networks, e.g., as slice consumer, slice provider, and slice constituent.

Although Rel-15 constitutes a rather early phase in 5G standardization to focus on specific solutions for drone operations, the incomplete study items in Rel-15 along with those in Rel-16 hint directions for future of standardization. Improvements of fundamental procedures (e.g., aerial-UE registration) for MEDs, definition of new terminal types, study on isolation of network resources for drones from security and performance aspects can be listed among standardization and research topics. Selected topics are discussed in detail next.

A. Network Configuration and Slice Design for WIDs

Traditionally, existing resources (e.g., infrastructure, transport network) are considered during network configuration and slice design. Meaning that the set of RAN nodes and NFs are pre-determined. However, versatility of WIDs adds degrees of freedom, and requires new design methods and configuration strategies.

1) RAN NSS design: An architectural role for WIDs (Sec. III-B2) that best fits the network need and situation must be selected. For instance, if the terrestrial nodes are eNBs, CU/DU is not an option; AR can be preferred. That requires WIDs that are capable of handling all control plane and establishing reliable Xn links with eNBs. If gNBs and 5G UEs are majority, WID can be deployed as a DU. In that case, split option must be determined based on fronthaul connection capability, technical specifications of the WID, and the need of the network (e.g., alleviating congestion, or increasing coverage). Donor-nodes, reliable topologies, and resource allocation strategies (e.g., hard slice, soft slice, updating RRMs) must be configured appropriately.

2) CN NSS design: Impact of integrating WIDs on 5GC must be minimized by utilizing flexible networking techniques while satisfying communication requirements, such as security, isolation, and latency. For that purpose, modifications on existing CN NSS, e.g., initializing new NFs, or increasing capacity of existing resources can be performed. TN capacity must be assessed, and additional capacity should be allocated, if needed. If WID-integration-slice is a newly created slice, AMF, NSSF etc. should be re-configured and new UPFs are created. SMF may be pre-configured with UPF selection for reducing latency. Moreover, MEC functions to provide additional computation for WID/MED operations may be deployed strategically.

Automated design to satify network requirements is key to agile networking. In addition to technical issues of design, business roles for WIDs are discussed next.

B. Support For New Business Models

Business models for MEDs are similar to those for UEs. For instance, the control link of an MED may be a high-priority link, such that in case of congestion, specific resources may be reserved for them to prevent outage. Ultimately, MED cases are likely to be supported via evolutionary standardization, configuration and application methods.

On the contrary, business models for WIDs can be complicated and diverse (Fig 4(b)):

Aerial-IaaS: This applies when WID acts as a single node, that is similar to a NF. WIDs can serve as access points, or VNFs, i.e., *drone-as-a-VNF*. For instance, when MME is malfunctioned, congested, or more reliability is needed, a drone with MME functionality can be utilized. For applications requiring low-latency, a drone can be utilized to bring application function closer by *drone-as-MEC*. In cases depicted in Fig. 3 and Fig. 2, a WID is used as an access point in an appropriate architectural role.

Aerial-NSSaaS: Multiple WIDs can form an *aerial network slice subnet* (A-NSS), e.g., overlaying an existing RAN-NSS or 5GC-NSS (e.g., UPFs, MMEs, and MEC applications).

Assuming an operator obtains WID services from a service provider (SP), a trade-off occurs between the operators aiming not to expose information, and SPs aiming not to delegate management capabilities. For instance, if a SP manages an A-NSS, then the operator needs to expose information, such as service types/requirements and user contexts, to the SP for fine-tuning management, e.g., PM. While diverse business models increase flexibility of WID services, and reduce the stress on operators, exposure of information and management capabilities become critical issues.

C. New QoS and KPI Parameters

There will likely be a need for new KPI and QoS parameters for MEDs and WIDs. For instance, since WIDs are deployed on-demand, their services should generating enough revenue. Although the number of served users can be a nominal KPI parameter, considering more complex charging schemes, it may be inadequate to determine profitability of WID operations. Hence a new KPI, *profitability of WID*, can be considered, which would involve charging policies, operation cost, and number of served users in formulation. We propose *integration efficiency* as an umbrella-KPI considering 5GC impact (e.g., additional load and signaling), RAN impact (e.g., resource allocation, interference), performance degradation for UEs in the cells of donor-nodes (e.g., due to interference, or scarcity of resources), topology efficiency (e.g., number of hops, reliability). KPIs for drones will need to be merged with new KPIs, for which some examples can be found in [15].

V. Conclusions

5G provides a wide array of design options from relaying to cloud-RAN. Therefore, there is no single and simple answer on how to utilize drones. Assessing deployment strategies based on information on network situation, and the characteristics of the demand/need is necessary. While the standardization activities already began for aerial-UEs in RAN, studies on DC, IAB, and NR-U can expedite integration of WIDs by enhancing energy savings, flight time and seamless integration. Core networks are not exempt from difficulties of integrating WIDs as new nodes, and many challenges can be listed from efficient slice selection to scalability. However, support for slicing and modularity of network functions provide means to tackle these challenges.

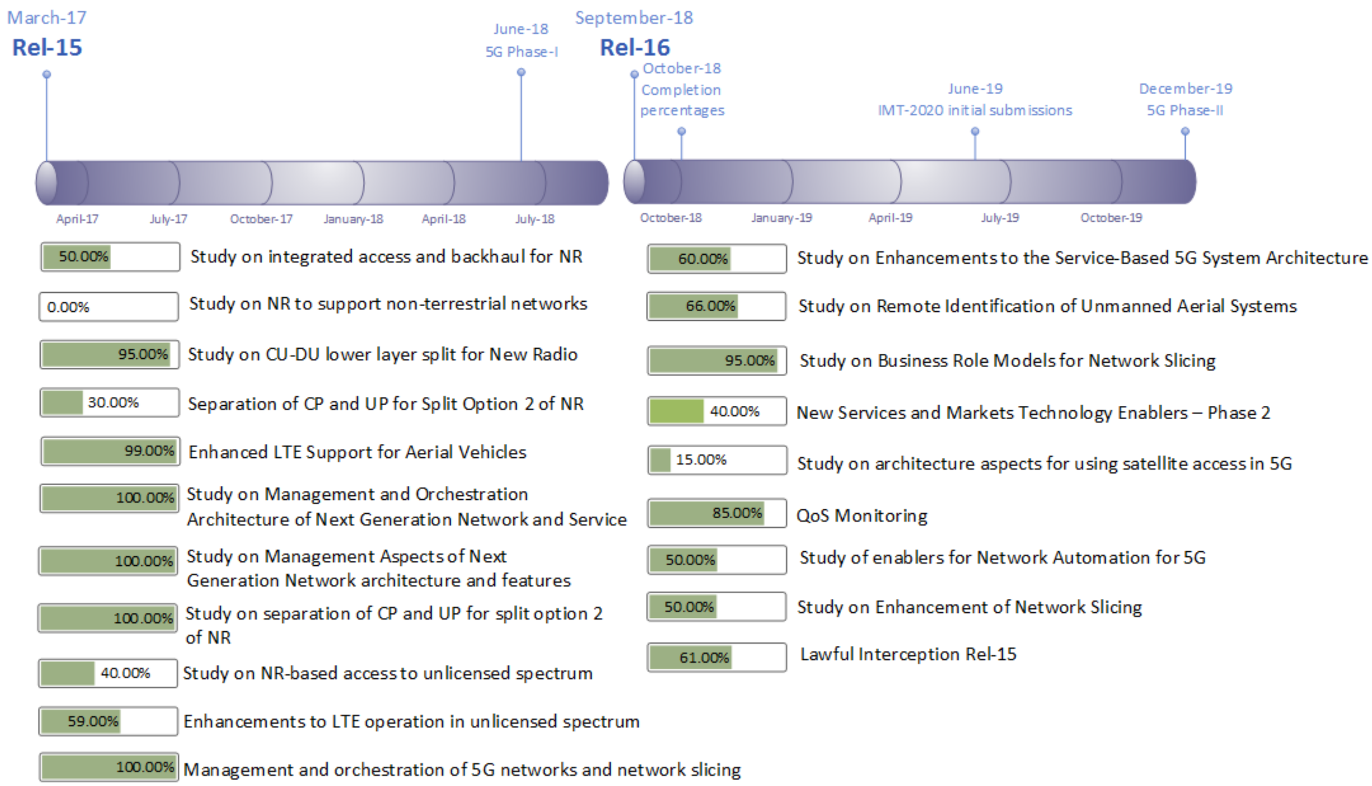

Fig. 5: Rel-15 and Rel-16 timeline with completion percentage of selected work items as of November 2018.

Despite accomplishments, a number of issues remain for each part of the network. Evaluating existing methods from the aspect of WIDs (e.g., split options, IAB methods), ensuring isolation (e.g., granular performance management, slicing), adaptive network design, end-to-end network data collection and analysis, defining new KPIs and QoS parameters, and supporting new business models can be listed among others. Furthermore, assessing existing designs of drones with respect to 5G standardization, designing new drones to serve as WIDs, and determining what type of aerial systems are suitable for 5G are another aspect that requires thorough studies. Nevertheless, a connected future is on the horizon for drones.

Acknowledgement

The authors would like to thank Hang Zhang, Bill Gage, Chengchao Liang, Ngoc Dao, Sophie Vrzic, Jaya Rao, and Xu Li with Huawei Technologies Canada, Co. Ltd., for their invaluable comments and discussions.

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