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Using 5G to Bring More than just Bits to Homes

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Abstract— **Future drone delivery infrastructure and service for distributing goods to inner city and rural areas, by collaborating with the already existing transportation system, has become an important function in the semi-/full-automation process of home deliveries. This has been exacerbated by the current (and possible future) Covid-19 pandemic. This paper presents a new paradigm for a 5G enabled drone delivery system based on ground-aerial integrated mobilities called TWIN that provide a high-quality communication system for increased drone fleet service capacity. We depict the 5G architecture that supports the dual mobilities and emphasize the strategies to ensure reliable, low latency radio link, high accuracy drone positioning together with location management. The increased link level availability coupled with high accuracy location management, allows for a series of new network applications and support the fast creation of drone delivery services. We envision that logistic services on the TWIN concept will have a high societal and economic impact for both urban and rural areas.**

Keywords—5G, Autonomous Drone Swarms; Mobile Edge Computing; Network Slicing; Urban and Rural Area Environments.

I. INTRODUCTION

The social distancing during Covid-19 virus epidemic forces us rely on remote working from home using all means of wired and wireless network accessing technologies. Services that can provide real support in homes with less human contact are highly recommended during the current pandemic or in other similar situations in the future. Even though more and more people are increasingly ordering over the Internet from on-line retailers, the home delivery services still rely on third party delivery services providers. This is a very labor-intensive occupation that often contributes to CO_2 emission, traffic congestion, puts the couriers in danger and, also, increases the chance of virus spreading. To use the drone for first/last mile of urban and rural areas, logistics could significantly increase the efficiency of delivery services provider operations.

Using drones as the means for product delivery is not a totally new concept. Amazon has started the Prime Air autonomous drone delivery project from 2016 and made the first Prime Air [15] parcel in Dec in the same year in Cambridge, UK. Start-ups like Zipline started providing medical products delivery in Rwanda using drones [16]. However, for making drone delivery a regular option for most of the small and medium-sized online retailers (like fresh food eCommerce and even local grocery stores), some current technical and regulatory limitations for practical drone operations, which are inhibiting the use of drones in the first/last mile, still need to be addressed. These include unreliable connectivity, positioning errors, unmanned traffic management, limited throughput from drones, power constraints, and regulations on operational security and beyond visual line of sight (BVLOS) operation safety. Developing countries, in Africa, may become early adopters of drone delivery due to urgent requirements for distribution of medicines. Similarly, in rural EU, drone delivery increases the accessibility of medicines for people living in remote areas. Drone medical delivery in rural areas in developing countries is not only a business opportunity, but also an opportunity to improve wellbeing and equality.

In this paper, a groundbreaking concept called TWIN is proposed to explore the possibility of drone delivery as a regular logistic option for diverse businesses. The key catalyst of the TWIN concept is the 5G network and its related features like network slicing and mobile edge cloud. The particular characteristic that makes the TWIN a potential widespread drone delivery concept is the 5G enabled integrated and interactive (twinned) ground-aerial mobilities: different from the conventional individual autonomous drone or drone with pilot, the TWIN concept will use a mobile ground support station (MGSS) as a carrier to accommodate a drone fleet to provide high drone throughput and high service capacity. With the support of MGSS, the drones can be seamlessly embedded to the existing transportation system for most of the journey, only to be released at the hot spots. The drone operation range and duration can be extended with the carrying, charging and monitoring support of a MGSS. To integrate dual mobilities, 5G becomes the ideal choice as it introduces the following capabilities: ***i) Virtualization:*** MGSS and associated software functions as part of the 5G infrastructures and virtualized network functions (VNFs) for quick service creation; ***ii) Network Slicing:*** (chaining of VNFs from different domains) to ensure availability of resources for reliable 5G link for specific logistic service and user. Also, the orchestration provides mechanism for network slice life-cycle management; and, ***iii) Mobile Edge Cloud (MEC):*** the computing and storage resources at the edge of the 5G network (RAN) provides low latency E2E service and opportunity for sensor data fusion based on high accuracy drone positioning service that is

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essential for drone operation. In addition, the MEC also provides the accommodation of the local Unmanned Aircraft System Traffic Management (UTM) that support the high drone throughput in the hot spot where more drones are required to fill the service needs.

For the rest of the paper, we provide two envisioned use cases of the TWIN delivery system followed by the analysis of the main technical requirements and the overall TWIN architecture. The detailed strategies for achieving the high-quality link, accuracy positioning, mobility management and featured network applications are elaborated. Lastly, we give the impact of the TWIN concept on urban and remote delivery.

II. TWIN DELIVERY SYSTEM CONCEPT

In order to deliver real substance rather than just information to households, we conceive two scenarios that use the 5G infrastructure to reach the residents in urban and remote locations. For both scenarios, the integrated ground-aerial mobility platform: ***i)*** Contains 5G infrastructure within it; ***ii)*** Acts as a mobile ground support station (MGSS) (e.g. VS01 [11]); and, ***iii)*** Deploys delivery drones.

A. URBAN SCENARIO

Fig.1 – Drone delivery in urban scenario

The TWIN delivery concept in the urban environment is depicted in Fig. 1. The MGSS, provides ground mobility, whilst carrying a fleet of delivery drones to seamlessly utilise the two transportation systems and produce a high throughput delivery service within the range of the hot spots. To support the drone fleet (high throughput) operation, the MGSS provides UTM, drone fleet and delivery task monitoring and scheduler support for drones. In the conventional configuration, MGSS also provides the drone connectivity via the license-free spectrum (e.g. 2.4 GHz for 802.11 standards family). However, the link quality and coverage may not always fulfill the needs of drones in high density urban areas. Also, the GNSS performance deterioration which can be caused by the Urban Canyon effect, makes the drone operation safety a pending factor. Thus, to support the ground supported drone deliver service in urban areas, a telecom-grade reliable and low latency radio link is needed. This is necessary for providing drones with high accuracy positioning and mobility management that is vital for drone delivery operations and which can be provided obtained in the 5G context using a mobile edge cloud (MEC).

B. RURAL SCENARIO

The TWIN delivery concept for remote areas is shown in Fig. 2. In this scenario, the MGSS extends the drone's operational range to remote areas that are beyond the limitations of the battery capabilities carried by an individual drone. One obvious difference from the urban scenario is the potential lack of telecommunications infrastructure in some rural areas (5G in the context of this paper). Thus, in the rural scenario, a tethered drone will be released to create the 5G backhaul link with far-end 5G gNB. The tethered drone provides the radio link for other delivery drones via either a license-free or a licensed 5G spectrum. The MGSS in rural scenario provides similar functions as in the urban scenario, however, with one major difference: the MGSS is required to host some MEC functions on an onboard monitoring entity that would have otherwise resided on the gNB MEC.

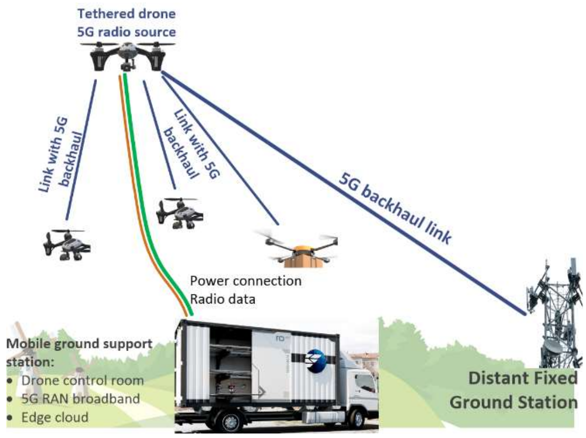

Fig.2 – Rural Use Case

C. TECHNICAL REQUIREMENTS TO SUPPORT USE CASES

Based on the above description of the two twinned-mobility delivery system use cases, we notice some key technical features that need to be supported by the 5G infrastructure:

- **Reliable link**: As the TWIN system is supposed to support mobilities in both ground and aerial, having a reliable (low block error rate) and low latency radio link is a primary requirement for the safe drone operation.
- **Localization and location management**: Complementary method that provides very precise real time drone UE positions on top of the GNSS measurements in the crowded urban environment while keeping a high refresh rate for safe motion control. In addition, the location management functions need to be provided to support the UTM, path planning, collision avoiding mechanism design, etc.
- **Processing power on the edge**: To ensure the low latency link and high positioning refresh rate, the processing of the information has to be moved to the network edge for avoiding the time and processing delay spent on the transport network and central data cloud (sometimes across different geographical domains).
- **Vertical supporting NetApps**: Based on the 5G infrastructure, generic network functions and featured functions that are designed to support the localization

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accuracy, the security and safety of drone operations, network applications (NetApps) are necessary to support the agile service creation based on the TWIN delivery concept.

The above features are supported by the TWIN system from the structural design of the architecture and the software running on the infrastructure and elaborated in Section III to VI.

III. 5G Architecture to Support Twin Mobility

A. Overall 5G Infrastructure Design

To support the technical requirements described Section II, the systematic enhancement of the 5G network is needed to support the development of a highly reliable radio link, accuracy UE localization and variety of the value-added Network Functions (NFs) for location management and drone control. The overview of hardware and software architecture is shown in Fig. 3.

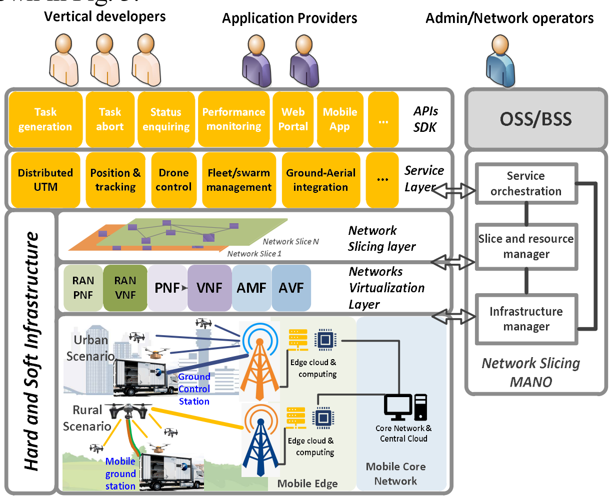

Fig. 3 – Overall System Architecture (hardware and software)

- **Integrated 5G infrastructure with mobile participants as network resources:** Different from the conventional 5G infrastructure which only targets on information distribution and networking, the TWIN system will also embed the delivery drones (aerial mobile resources for substance carrying) and MGSS (ground mobile resources for drone charging, task scheduling and UTM) as network resources to support substances distribution.
- **Virtualization of infrastructure entities and network functions**: The generic 5G network components, NFs, the resources of mobile participants and functions running in the mobile drone participants are abstracted as virtualized infrastructure and NFs that can be chained flexibly as network applications or network slice to support agile logistic service creation.
- **Mobile edge computing/cloud**: the MEC is added into the TWIN infrastructure. Firstly, to reduce the system latency by completing the intelligent processing on the computing units close to the gNB and allowing the data fetching from local storage. Second, to save the mobile nodes (drones) energy by apportioning an intelligent processing load from mobile node to gNB. In addition, when positioning function is considered, MEC provides extra benefits by aggregating the multiple drone locations in a local center for location related service development.
- **Cross-domain network slicing and orchestration**: As an end-to-end (E2E) logistics service, provisioning will have to assemble the virtualized infrastructure components and functions of 5G networks, drones and MGSS that are very likely from different operators or owners (domains). Thus, to support the TWIN delivery concept, the cross-domain network slicing will be the key mechanism to book core, transport and even access networks and UEs (drones) and MGSS resources across operation domains that are needed for a quality guaranteed service. Correspondingly, the cross-domain orchestrator will also be provided for slice life-cycle management.

B. The Expermental Platform

A cross-domain 5G infrastructure is needed as experimentation platform for the service provider to test and create the drone delivery applications.

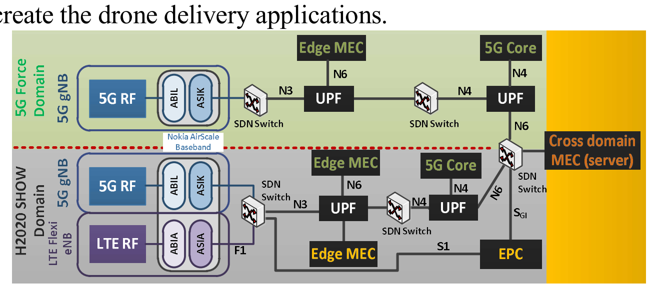

Fig. 4 – Cross Domain 5G Infrastructure

As shown in Fig. 4, the TWIN experimentation platform consists of the 5G Force [12] and H2020 SHOW [13] domains, that are conceived to be standalone (SA) and non-standalone (NSA) configurations respectively. 5G Force consists of Nokia AirScale [17] baseband ABILs, which are used to receive the 3.5 GHz (Band 43, 60 MHz bandwidth) 5G RF signal by using AEQA TDD 64T64R Adaptive Antenna. The RAN will be connected to SDN switch that routes control plane N1 and N2 to the 5G core network, which allocates a local UPF directly connected with Edge MEC server. After the UPF and Edge MEC have been allocated, the user data N3 is sent from the SDN switch directly to the UPF and Edge MEC server from 25 GE backhaul interface (SFP28) ports on AirScale ASIK.[2] The 4G LTE aspect of H2020 SHOW domain incorporates eight Nokia Flexi Zone Micro Outdoor on Band-38 (2.6 GHz) eNBs. The AirScale baseband ABIAs are used to receive the LTE RF signals, and then the LTE data is sent to an SDN switch from the 25 GE backhaul physical interface (SFP28) ports on AirScale ASIA via the F1 logic interface. From the MEC, the LTE mobile data is directed to the 4G Edge MEC via S1 interface and sent to the evolved packet core (EPC) through an SDN switch. The 5G edge MEC and core network, which are configurable in the H2020 SHOW domain are the same as the 5G Force domain. In addition, a cross-domain server will be deployed to gather the user data from both 5G Force and H2020 SHOW domains for multi-domain orchestration, service management, operation, business support system (OSS/BSS)

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and service portal for the drone delivery and logistics applications.

Hence, the proposed system architecture, combined with the cross-domain server and edge MEC servers, can enable drones to ***i)*** connect to multiple different operators, ***ii)*** use multiple different devices registered to different operators; and, ***iii)*** exploit license-free spectrum for accessing the Internet or Mobile Network.

IV. High Quality Link for Drone Operation

Similar as in the case of autonomous driving, ultra-low latency and extreme high reliability are the essential requirements for the safe drone operations. In the 5G NR context, it is referred to as a URLLC service whose latency falls in 1 to 10 ms and Block Error Rate (BLER) is below 10^{-9}. Table I shows the latency and reliability requirements of some typical scenarios mentioned in [14], which are of referential significance in the drone operations, especially in the short range high density city context.

Table. I Example of URLLC scenarios and corresponding requirements

Scenarios	Latency	Reliability
Discrete automation control	1 ms	99.9999%
Remote control	5 ms	99.999%
Intelligent transport system – infrastructure backhaul	10 ms	99.9999%

Usually, there are two ways to approach the URLLC requirements: ***i)*** lower layer radio network approach; and, ***ii)*** higher layer network architecture level resource ensuring mechanisms. The former approach includes a 5G New Radio numerology, transmission time interval (TTI) and micro-diversity in physical layer; applying of scheduling policy, the uplink grant-free transmission, high reliability control channels (e.g. Packet Data Convergence Protocol packet duplication) and Hybrid Automatic Repeat reQuest (HARQ) enhancement in the radio link control layer. The TWIN concept focuses on the network architecture level ensuring mechanism.

The TWIN delivery concept leverages the MEC and network slicing (chaining of the NFs) in Section III-A to approach the high reliability and low latency required by drone operations. The network slicing guarantees and isolates enough resources for specific applications without competing for the resources with other services or users during the service cycle, thus, ensures the connectivity reliability. In context of the TWIN concept, it refers to core network, transport network, MEC resources and the VNFs that invoke the PHY and RLC layer mechanisms mentioned in last paragraph. For the long run, the RAN slicing is also considered with the evolution of the whitebox hardware and standardized interface promoted by the organization like O-RAN Alliance. The MEC on the gNB rules out the time delay caused by transport network and core network and provide intelligent processing for real time feedback for drone control over the network. This fast feedback loop on the network edge is the essential feature that enables the drone motion control, swarming in the urban context.

V. Fine Grain Localisation Data Fusion & Mobility Management

A. Drone Localization Enhanement

The GNSS provides 2 m accuracy and 10 Hz update rate in general good conditions. The performance deteriorates in the city environment due to the urban canyon effect and the multiple signal reflections. Thus, the sole use of GNSS will not be able to provide robust positioning support for safe drone operation in TWIN delivery system. A two-step information fusion-based strategy will be used in the TWIN concept to provide accurate positioning functions, update rate, time to first fix (TTFF) and power consumption on top of the raw GNSS measurement. The information fusion-based positioning is composed by multiple *sensor information aggregation* on the 5G drone UE as the first step and *location information fusion engine* in MEC as the second step.

- **Sensor Information Aggregation**: This operation takes place on the drone UE. Besides the GNSS, there are additional sensor data on the drone that contain location information or information to keep track of the drone's position. For example, the inertial measurement unit (IMU) provides the orientation, acceleration and displacement of the drone to estimate the drone trajectory. The extracted street scene for drone camera can be used to localize the drone by matching the perspective on the 3D street map. Also, the RSS and RSRP vector measurement from the multiple gNBs on the drone provide another layer of data to reflect the relative spatial relation between the drone and base stations. The variety of the onboard drone radar sensors also provide altitude, ground imaging and major objects ranging and angle to complement the 3D positioning of the drone. All these location related sensor data will be aggregated in the drone on-board computer and tagged with timestamps and raw GNSS positions for fusion. However, due to the power constraints, limited computing and lack of the map data support, the on-board drone companion is not suitable for fusion processing. Thus, the tagged sensor information will be forwarded to MEC fine-grained positioning information estimation.

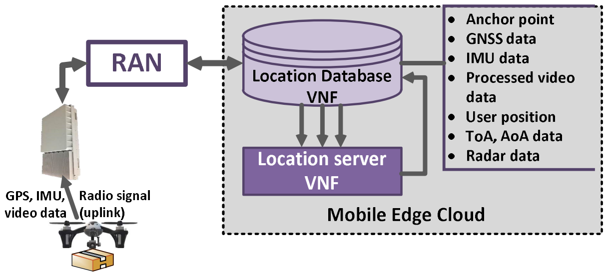

Fig. 5 – Maximum received power-based cell association patterns at ground

- **Location Information Engine**: 5G edge computing for positioning consists of a Location Server (LS) which is a Virtual Network Function (VNF) within the Mobile Edge Cloud (MEC) whose sole purpose is to continually process raw location data from the Location Database (LD) and output the drone UE final estimated location back to the LD. The use of a Software Defined Network (SDN) allows for direct communication between the LD and LS using the Forwarding

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Device (FD). Fig. 5 illustrates the general components involved in the localization process.
The configuration tables within the LD, the 'Anchor points' table, stores all the priori known antenna estimated location that can be used in the positioning algorithms. The LS retrieves the relevant data from the Anchor points table as well as two other LD tables which contain the tagged sensor readings from the drone. With these data the LS performs the location estimation calculations and store the final position estimates in the 'User Positions' table in the LD. Kalman Filter (KF) is used as main location estimation and calibration even for the dead reckoning the raw GNSS location. In practice, we can preload Extended Kalman Filter (EKF), Unscented Kalman Filter (UKF) and Particle Filter in the MEC at the same time in case the linear KF does not reach the performance requirement. Particularly, with the computing power in MEC, the PF may be the best candidate because of its high performance in nonlinear scenario.
Besides the tracking filter, we introduce the context-awareness in the positioning strategy in TWIN delivery: The main purpose for introducing the context-awareness is to reduce the data transmission between the drone UE and gNB. By using the aggregated multiple sensors in MEC, supervised classification and unsupervised clustering can be used to categorise the drone operation environment into a certain number of scenarios. The localizing engine can use the selected sensor combinations, rather than always using all sensor data for positioning, and in that way, reduce the data request from the UE and reduce power consumption of the UE. The context training/clustering will be done on the MEC to take advantage of the computing power, while the trained model will be loaded on the drone UE to recognize the contexts and select sensor combinations.

- **Future-oriented 5G Radio Positioning**: The 5G radio front-end is often equipped with an array antenna (for example, the TWIN experimentation platform is using 64T64R massive MIMO array) which enables the high accurate angle of arrive (AoA) and time of departure (ToD) estimation of the drone UE by using Sounding Reference Signal (SRS). The 5G radio-based UE signal ToA and ToD can be used as one type of sensor date can be used in the Location Information Engine. However, the AoA and ToD are vendor-depend information which rely on physical layer processing as well as the openness of RAN and are not always available for use in the MEC. Without loss of generality, we will reserve the space in LD database and interface in LS algorithm for the 5G signal based AoA and ToD estimation as a future option.

B. Mobility Management

The safety and operation of drones can be significantly enhanced when remote command and control signals are able to be issued. Such command and control communications need to be reliable, and the packets should be successfully delivered (depending on the use case) within some latency bound with high probability.

4G BTS antennas are typically tilted downwards by a few degrees. The main lobe of a 4G BS antenna thus covers a large part of the surface area of the cell to improve performance for terrestrial UEs [2] and at ground level, the strongest site is typically the closest one. However, a drone UE may be frequently served by the sidelobes of BS antennas, which have lower antenna gains. It was predicted in [2] that the coverage areas of the sidelobes may be small and the signals at the edges may drop sharply due to deep antenna nulls. At a given location, the strongest signal might come from a faraway BS, if the gain of the sidelobes of the closer BSs to the drone UE is much weaker. Prediction of these effects are shown in Figure 6, which shows the maximum received power-based cell association patterns at ground level and at the heights of 50 m, 100 m, and 300 m.

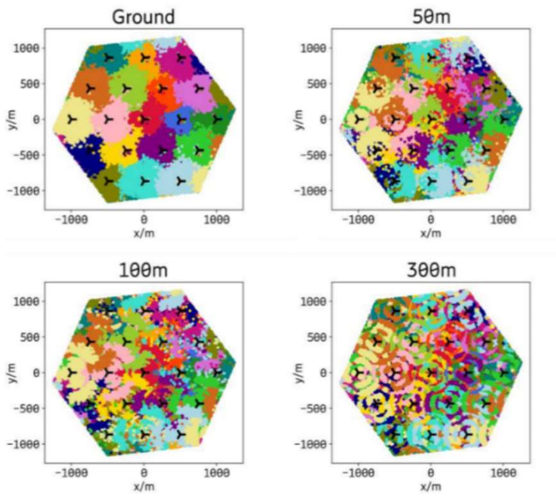

Fig. 6 – Maximum received power-based cell association patterns at ground level and at the heights of 50 m, 100 m, and 300 m (courtesy of [2])

At the higher altitudes, the coverage areas become fragmented and the fragmentation pattern is determined by the lobe structures of the BS antennas. These predictions were validated with Reference Signal Received Power (RSRP), Reference signal received quality (RSRQ) and Signal to Interference-plus-Noise Ratio (SINR) downlink received signal quality measurement from drones [2]. The net effect of this is that mobility handover may be unnecessarily triggered between these fragmented sidelobe areas at these higher altitudes thereby generating a large signaling load. Measurement results of the physical uplink shared channel (PUSCH) presented in [2] showed that throughputs at the heights of both 50 m and 150 m are higher than the corresponding values at ground level. The drone UE likely experiences much better uplink channel conditions because there is close to free-space propagation conditions in the sky when compared to the propagation conditions on the ground [2]. AI guided mobility management techniques can be used for known drone UEs that take into account drone position, altitude and RSRP, RSRQ and SINR downlink measurements and PUSCH uplink measurements in handover decisions.

C. Drone Mobility Management

The control a fleet of delivery drones to perform delivery tasks are performed by Virtual Infrastructure/Network

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Functions (VXFs) that are organized into Cognitive, Monitoring and Control planes. The structure for mobility management and drone location-based service is shown in Fig 7.

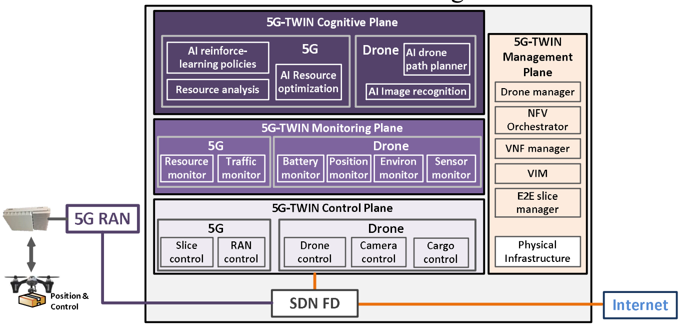

Fig. 7 - 5G-TWIN mobility management and location

Whilst it is clearly mandatory that certain functions are required to be processed by VXFs entirely on the MEC, for other functions, since there may not be a large amount of processing power available on board of the drones, an important part of the proposed architecture design will be to ascertain what processing can be performed on the drones and what is required to be processed by the VFXs in the MEC on the MGSS.

At the Cognitive plane, the AI Drone Scheduler and Mission Planner is responsible for scheduling and planning delivery tasks based on its task assignment and knowledge of its destination and current state for example position, battery state, grabber, cargo station load status etc. and the state of its environment sensed by video cameras and analyzed by an AI Image Recognition system which is remote from the drones. For example during landing it monitors the position of the landing zone, during flight it monitors the drone's environment to scan if there are any objects it could collide with, and during picking/dropping up of cargo it monitors the position of the cargo relative to its grippers for a successful access/release of its cargo. The Cognitive Plane VXFs are highly dependent on the input from Monitoring Plane VXFs in order to make artificial intelligent analysis and decisions, which in turn will transmit action commands to the Control Plane VXFs. The AI Drone Scheduler and Path Planner therefore must also have an interface to the UTM system.

At the Monitoring Plane, VXFs need to continually monitor and keep a record of drone status, for example, its Battery, Position, Environment, Gripper Status, etc. These systems enable the AI Drone Scheduler and Path Planner to make strategic decisions about the drone's path. The Control Plane VXFs receive commands from the AI Drone Scheduler and Path Planner to action drones' speed and bearing using the Drone Control VXF, to action the drones' or its camera' attitude / orientation (typically roll, pitch and yaw) to make observations in the required direction using the Camera Control VXF and to control the drones' grippers or cargo pully system using the Cargo Control VXF.

VI. Network Applications for Vertical Services

In virtualized 5G networks, the different physical infrastructures are virtualized to support different virtual infrastructures, administratively managed by different owners. This infrastructure virtualization allows service providers to run on the cloud transparently without worrying about the physical resources. The 5G specifications allows for private 5G networks for vertical businesses and other enterprises to share infrastructure between public network operators to provide E2E service provisioning by supporting multi-domain interoperability.

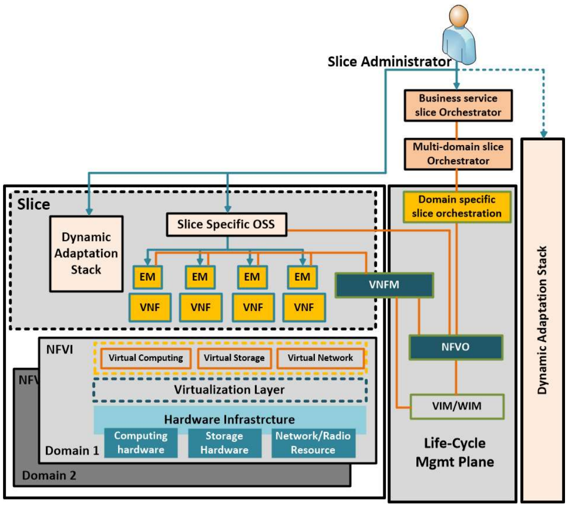

Fig. 8 - Conceptual multiple domain network slice architecture

The dynamic management of NetApps in the context of logistics-oriented tasks require optimal management of the necessary VNFs for adequate utilization of resources that spans from the applications running on drones to the backend services, including in the middle of this virtual chain of radio resources, MEC applications, Control and Data Plane functions as well as the application specific VNFs. Multi-domain interoperability can be provided by a dynamic and layered slice control and management to accurately address the business domain's demands as shown in Fig 8.

The following NFs are foreseen to be administered for the provision of the value-added network services:

- **Network slicing** create new and planned modifications of existing slice components for usage by other verticals by extending appropriately their life cycle utilization profile and cross-dependencies are identified for instantiation for computing resources (on UE), MEC, Access and Core, Cloud and inter-domain infrastructure resources.
- **Service function chaining constraints** are enforced to allow for proper management of network flows among control, data plane and application specific functions. As different segments (Drone/UE, 5G/4G, MEC, Cloud, and cross-domain data path) are involved in the setup of the overall business slices, chaining per segments builds on top of the segment-involved technology.
- **5G infrastructure control plane VNFs** provide the control plane protocols required for the interoperability of the fog computing resources (on UE), MEC, Access and Core, Cloud and inter-domain infrastructure resources.
- **5G infrastructure user plane VNFs** provide the data plane protocols required for forwarding packet data.

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- **Network and application security** are required for authentication, registration, identification, neo-awareness, network traffic analysis, behavioural analysis, detection of abnormal network access and emergency actions.

The drone in the TWIN concept is designed to carry a 5G UE, GPS, microcontroller (known as a Companion Computer) two miniature cameras (one facing forward and one facing down) and a pair of grippers to carry and release a cargo. As there is not much processing power on the drone Companion Computer, all important signal processing related to the drone will be performed on the MEC as VNFs and the results of this returned as control commands to the drone. These VNFs are organized in three planes, namely: Control, Monitoring and Cognitive:

- **Drone and ground station positioning and tracking VNF** uses data fusion to ensure the Drone UE has a high accuracy and stable position information. It consists of three components: ***i)*** location information fusion engine in MEC; ***ii)*** Sensor information aggregation on the drone; and, ***iii)*** Radio based Time of Arrival (ToA) and Angle of Arrival (AoA) measurements using the RAN.
- **Drone Unmanned Traffic Manager** at the local level manages drone flights scheduling, flight path and landing coordination while at global level identifies collision risks and offers a de-confliction solution to modify at least one of the drones' path to avoid the risk of collision. It considers the drone performance and type of mission, as well as external elements such as terrain, obstacles and weather.
- **Drone fleet management VNF** requires coordination and oversight in order to optimize the use of drones within a fleet and ensure safe operation. The focus is on optimizing the delivery plan and schedule, based on the missions to be performed by the fleet.
- **Operations control room VNF** allows to display air and ground information, including the status of drones as well as station assets. May exist at a central control office or at "mobile ground drone station" (MGDS) vehicle.
- **Drone control VNF** is responsible for controlling the overall speed, altitude and direction of travel of the drones. Imaging-based localisation VNF (in MEC) can determine position of a drone by comparing plan views of Google Earth with plan views images captured by the drone to determine position. Scaling of the images is performed from knowing the altitude of the drone using a calibrated onboard barometer. Images focus on using easily recognised landmarks on the ground for recognising position. The imaging-based location results are stored on an imaging location database in the MEC.
- **AI Drone Path Planner VNF** will take delivery tasks and plan a flight path for the drone swarm. The flight paths may be modified due to the existence of other drones, due to obstacles in the air identified by the cameras or due to the drone requiring to be recharged. Thus, the drone path is constantly being monitored so that the path can be revised as required.
- **Fallback VNF** uses a flight control cockpit similar to a flight simulator gaming cockpit to remotely fly the drone. The system uses VR headset to provide the pilot with a 360-degree view of the environment from the theta-V camera on the drone There may also be a virtual dashboard superposed in 360-degree camera view which can be controlled from haptic devices on the pilot. Interface to the UTM VNF is required to request for and obtain control of any one from several drones. During remote driving of a drone, the pilot must constantly be made aware of the status of the other drones in the fleet from the virtual dashboard.
- **Network key performance indicator (KPI) validation VNF** measures the main 5G KPIs that are interesting to the drone industry, namely: bandwidth and latency so that video can play a role in remote piloting of drones especially with guaranteed connectivity assured by network slicing and so that localisation and navigation using video image analysis on Mobile Edge Computing platforms can make drones more autonomous especially in places where GPS and other localisation technologies fail to work. This is very important for obtaining regulatory approval to operate drones out of out of visual line of sight.

VII. Other Applications

Aside from the stated applications presented in the previous sections, there are a number of other areas in which 5G-TWIN could provide significant value. Lifting the current limitation on the volume of data that can be processed in realtime will mean that the following applications are significnatly enhanced: Geological surveying; Civil engineering inspection and predictive analytics; Construction support including realtime health and safety monitoring; Aerial photography; Geographic mapping; Disaster management; Precision agriculture; Search and rescue; Weather forecasting; Wildlife monitoring and Law enforcement; and, Border control surveillance.

VIII. Conclusions

The following conclusions are drawn from this work:

- Drone delivery is predicted to grow with a 44.7% Compound Annual Growth Rate to 2030 when it will be worth an estimated $27.4b. Within this market, the light package (<2 kg) segment is projected to be the most popular and lead the sector. The use of drones in the first/last mile of urban and rural areas logistics could significantly increase the efficiency of delivery services provider operations.
- 5G-TWIN has the potential to overcome current technical limitations for drone fleet operations in the first/last mile including: unreliable connectivity, positioning errors, operational security and safety, unmanned traffic management, limited throughput from drones, power constraints and operation beyond visual line of sight.
- This research proposes a framework for processing high volumes of data captured via drone fleets, facilitating numerous areas that are currently inaccesible due to the current on-board processing power of drones;

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- 5G-TWIN has the potential to deliver medicines, products and services to people in remote rural locations whilst simultaneously providing high-speed internet to these locations;

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