OPEN GENERATION UNCREWED AIRCRAFT SYSTEMS (UAS) USE CASES

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Abstract

The Open Generation consortium focuses on use-case driven innovation to identify and overcome safety and operational gaps and demonstrate enabling 5G solutions for emerging industry verticals. This document is an overview of the four UAS use cases that form the basis of the evaluations, testing, and experimentation during the first phase of the work in the consortium.

Introduction

Drones are being deployed for photograph/videography, inspection, mapping, and logistics, just to name a few areas of active industry interest. To unlock emerging applications of Uncrewed Aircraft Systems (UAS), the industry must develop and agree on the solutions required for safe and reliable Beyond Visual Line-of-Sight (BVLOS) operations. A key enabler of BVLOS operations is wireless communications. Cellular mobile networks offer wide area, high speed, and secure wireless connectivity, which can enhance control and safety of UAS operations and enable BVLOS use cases. The Open Generation consortium promotes the use of 5G mobile technologies for low altitude UAS applications, targeting operations at an above-ground height of up to 400 feet. The flexibility and enhanced capabilities of 5G networks are well suited to meet the requirements of different UAS use cases. The consortium selected four use cases representing a wide range of deployment options and covers the requirements of popular UAS use cases.

In the next sections, we review each of the selected use cases and describe an example operation. We summarize the respective communication requirements that we derived from different specifications and reports such as 3GPP TS 22.125, 3GPP TR 22.829, ACJA LTE Aerial Profile, and group consensus of the Open Generation consortium

Commercial Package Delivery via UAS

Many companies are interested in using UAS to increase product distribution, reduce product delivery times, and achieve corresponding potential cost savings. This use case is focusing on the last delivery segment of a package to its final destination from a distribution center. These delivery locations may be in urban, suburban, or rural areas—each of which presents unique challenges for the UAS operation as well as for the communication technology. We assume that the delivery drones are stationed at a warehouse infrastructure that allows loading/unloading of packages, and take-off and landing of multiple drones. Each drone is automatically programmed with a flight plan based upon the package delivery address, using the company's order fulfillment system. The warehouse has an internal private wireless network. When the drone leaves the warehouse, it needs to switch to a public communication network. In a high-density case, when many drones are operating at the same time at and around the warehouse, the communication networks will have to handle the high-density switchover from a local private to a wide-area public network. This use case will heavily rely on the public cellular networks for communication; therefore, coexistence with existing users and utilizing existing infrastructure are key considerations for our evaluations and identification of innovation opportunities.

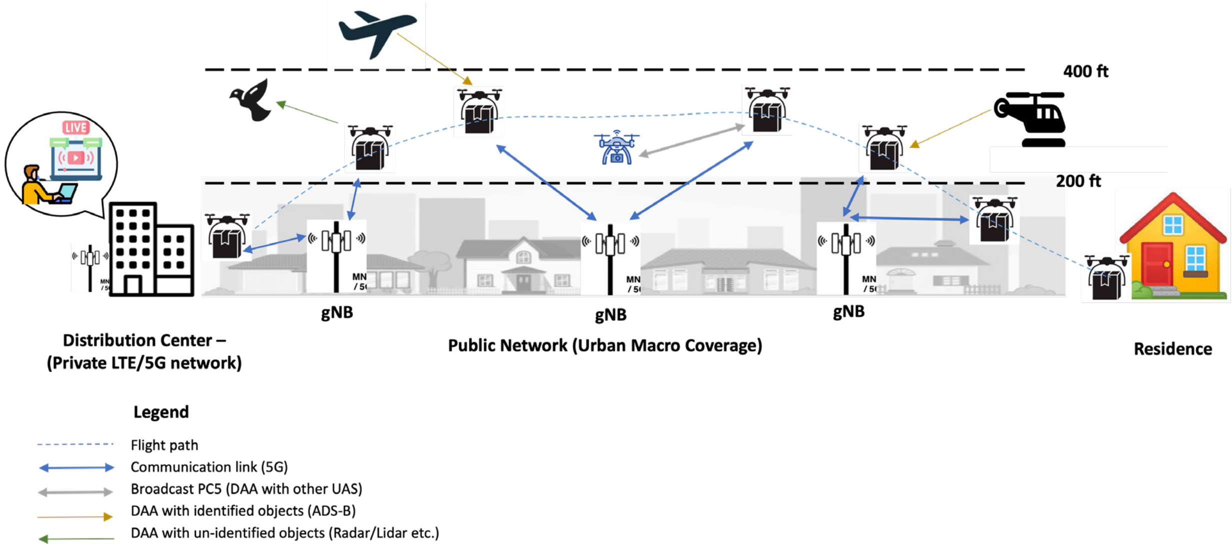

FIGURE 1. OVERVIEW OF COMMERCIAL PACKAGE DELIVERY USE CASE

Example operation

1. First, the end customer submits an order via an order delivery system for a package that meets conditions for delivery by a drone. The order triggers the fulfillment center package delivery systems to automatically load the package on a drone. In parallel, the drone is programmed with a flight plan by the fulfillment center flight management system. Additional data communications channels may be established with UAS Traffic Management (UTM) airspace management applications (e.g., for airspace authorization and real-time monitoring of airspace conditions), and inter-drone communication with drones in the neighborhood (e.g., via broadcast/ multi-cast in the control plane).
2. The flight management system manages the flight plan / safety checks for airworthiness and ensures the local weather forecast is within regulation and conducive for aircraft type.
3. The drone follows the predetermined flight path to its destination, which could include traversing across flight paths of other drones. The drone performs flight path maneuvers as directed by the Detect and Avoid System (DAA). The drone manages its speed, altitude, and bearing and initiates collision avoidance based upon cooperative communication with nearby drones and commands from UTM applications. Sensors onboard are used to map the flight path to physical contours to avoid buildings, power lines, bridges, light poles, etc.
4. In case of being notified of an emergency condition (e.g., due to the arrival of a

medical/police helicopter in its flight path), the drone can detect-and-avoid or be commanded to ascend/descend and change its bearing to leave airspace around the emergency aircraft. After avoidance, the drone resumes its flight to the destination.

5. Upon arriving at its destination, the drone performs maneuvers to exit the flight path and descend to the customer premises. While descending, the drone may communicate with other drones to announce intention to descend and get authorization from UTM, etc. The drone also uses sensors to safely descend (avoid humans, cars, street furniture, animals, etc.)

TABLE 1. COMMUNICATION REQUIREMENTS OF THE COMMERCIAL PACKAGE DELIVERY USE CASE

	Direction	Throughput (kbps)	Round-Trip-Time (ms)	End-to-End one-way latency (ms)	Reliability (PER)	Priority
Command and Control (C2)	Both	35	500		1e-5	High
Detect and Avoid (DAA) *Drone-to-drone*	Broadcast	35		100	1e-5	High
Detect and Avoid (DAA) *Manned aircraft to drone*	As described in the previous section	35	1000		1e-6	High
Mission Payload Image delivery	Ground, 10 ft, 30 ft AGL	1000	500		1e-3	Medium

6. The drone notifies the fulfillment order delivery system about the delivery and receives a new flight plan for the next destination or returns to the fulfillment center.

Static Infrastructure Inspection via UAS

There are 60,000 distribution substations in the United States energy grid. Efficient maintenance of many, and often remote, stations is a key industry challenge. Drone-in-a-box solutions provide potential remedies for costly inspections. An electrical distribution substation has a fixed geographic footprint, which is likely serviceable by a single communication network cell. The physical dimensions of an electrical substation can vary, but for this scenario it is assumed the facility covers approximately 7 acres, or a square of about 550 feet per side. Access to the substation is controlled; therefore, ground risk is more easily mitigated, making the safety case for remote BVLOS operations easier.

For this use case, we assume that there is a UAS stationed onsite at the substation for regular inspection dispatch. It is housed within a Ground Sensor Unit (GSU) when not flying. Only one drone is flown within the substation permitter. The Remote Pilot in Command (RPIC) and the Control Station (CS) are located off-premises and are not within visual line of sight of the drone. The drone is capable of flying preprogrammed flight routes but requires connection to a pilot over a network for the pilot to intervene as required. Therefore, network connectivity must exist onsite at the substation. The operational maximum altitude of the drone is 400 feet above ground level with a typical flight endurance of 30 minutes. The drone is typically programmed so that it slowly transits from one observation point to another, but it can fly at a maximum of 40 knots if required. The aircraft weighs approximately 20 pounds. The drone has both a 4K video and thermal camera, as part of the mission imagery payload, that is used to perform inspections of the substation equipment. The drone has onboard obstacle avoidance sensors that prevent it from flying into substation structures and can detect some other nearby aerial objects, like birds. It is not a detect and avoid sensor for identifying hazards such as other aircraft. The drone also contains a Broadcast Remote ID receiver (BRID) for detecting other drones.

The GSU contains a video system with one or more 4k cameras for visual confirmation of aircraft readiness before flight. In addition to housing the drone, the GSU contains a weather station, Automatic Dependent Surveillance-Broadcast (ADS-B) In receiver for detecting local air traffic equipped with ADS-B Out, and one or more means of detecting non-cooperative air traffic (primary radar, computer vision, acoustic sensors, etc.) that is connected to the local private 5G network. The GSU also contains a Broadcast Remote ID receiver (BRID) for detecting other drones.

It is assumed that the drone and GSU connect to the same 5G network. Additionally, the drone may utilize other cellular or RF links between it and the GSU, if the primary 5G link is unavailable. See Figure 2 below for an overview of the scenario.

Example operation

1. The drone, GSU, and supporting infrastructure are installed onsite at the electrical distribution substation. The drone pilot and CS are located offsite of the substation at a utility-owned office. The drone, GSU, and CS may connect to a communications cloud service provided by the drone OEM.
2. On scheduled intervals or on an as-needed basis, the pilot prepares the drone for an inspection mission. She begins by configuring any flight-specific communications settings (such as thresholds between 5G and alternative link switchovers), remotely pre-flight inspecting it for visual airworthiness, assessing the health of the drone's onboard systems, and verifying the weather is within regulatory and vehicle specific minimums.

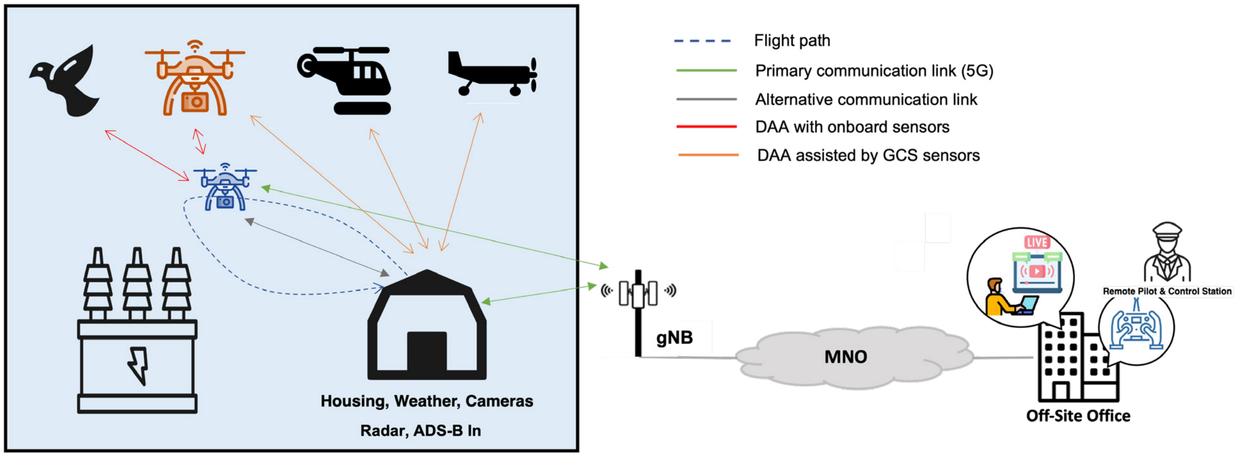

FIGURE 2. OVERVIEW OF STATIC INFRASTRUCTURE INSPECTION USE CASE

3. The pilot sends the drone a planned flight route and initiates the inspection mission. The aircraft ascends to its operational inspection height, clear of all equipment and nearby foliage (likely between 100 and 200 feet), and proceeds along its pre-programmed flight route. Throughout the mission, the pilot supervises the mission progress and health of the drone and GSU.

- The drone is capable of completing a pre-programmed inspection flight without manual pilot intervention from take-off to landing. Pilot intervention is primarily used to modify the flight route for imagery-collection improvements. In the event of an airspace risk, like an approaching aircraft, the pilot can manually alter the route and altitude of the drone.
- In a remote office, the pilot watches the inspection via live video and photo transmissions and notices an issue she wants a better view of. The pilot intervenes with the pre-planned flight route and moves the drone to fly closer to the point of interest. The vehicle's onboard obstacle avoidance sensors help ensure the vehicle does not collide with obstacles such as equipment or foliage. After the flight intervention, the drone returns to the pre-planned flight route. Alternatively, the video streamed from the drone is analyzed by computer tools (for example, artificial intelligence) to discover anomalies with the infrastructure and provides instructions to the aircraft to fly closer to a specific area requiring higher quality imagery.
- During a portion of the pre-planned flight route, the drone unexpectedly drops the primary 5G communication link. The long interruption of the dropped link causes the drone to automatically switchover to an alternative communications link. The pilot and GSU are notified that the drone is now operating on the alternative link. The alternative link is a direct line of sight link between the GSU and the drone. As such, all messages between the drone and CS are relayed via the GSU.
- Later during the flight, the pilot determines that a switchover back to 5G is possible. The pilot, using the CS, commands the drone to use the 5G link. Alternatively, the switchover back to 5G could occur automatically, based on internal drone settings and logic.
- During the flight, an emergency services helicopter flies overhead transmitting ADS-B Out. The GSU equipped with ADS-B In detects the emergency services helicopter and publishes that information to the drone and to the pilot. The helicopter's flight is low enough to break vertical separation requirements, so the drone automatically descends to a safe altitude until the helicopter has passed, all the while keeping the pilot informed of the invoked automatic behavior. Then the drone resumes its inspection mission.
- A few minutes later, a crop duster aircraft without ADS-B Out flies toward the substation. The crop duster is detected by the GSU radar and alerts the drone and pilot monitoring the drone. Based on the provided information, the drone determines that the crop duster is a potential airspace hazard. The drone automatically descends to a height safely out of the path of the crop duster and then resumes its mission once the aircraft has passed, all the while keeping the pilot informed of the invoked automatic behavior. Then the drone resumes its inspection mission.

- A few minutes later, a threatened raptor emerges from a tree 10 feet from the drone's position and flies toward the drone to attack it. The drone's onboard obstacle avoidance sensor detects the incoming bird and determines it is on a collision course. The aircraft pauses its pre-planned flight route based on established flight rules. The drone alerts the pilot to the oncoming raptor and the pause action the drone has initiated. The pilot is prompted by the drone if she wants to override the pause. The pilot does not intervene, the raptor flies away, and the drone completes its inspection mission.

TABLE 2. COMMUNICATION REQUIREMENTS OF THE STATIC INFRASTRUCTURE INSPECTION USE CASE

	Direction	Throughput (kbps)	Round-Trip-Time (ms)	End-to-End one-way latency (ms)	Reliability (PER)	Priority
Command and Control (C2)	Both	35	500		1e-5	Very High
Non-Critical C2	Both	35	500		1e-3	System Design
Detect and Avoid (DAA) *Drone-to-drone*	Broadcast	35		100	1e-5	Very High
Detect and Avoid (DAA) *Manned aircraft to drone*	Broadcast	35	1000		1e-6	Very High
Mission Payload Image delivery	To GCS (or Other Server)	25000		100	1e-5	Best Effort

- During the flight, both the drone and GSU detect a non-participating drone outside of the electrical substation area. Because it does not represent a collision hazard, the drone does not alter its preplanned flight route. The information is passed to the pilot for situational awareness purposes.
- Upon mission completion, the drone returns to the GSU and lands to be charged, off-load any remaining mission or drone data, shelter from weather, and await the command to fly again.

Emergency Response via UAS

Within the broad category of emergency response, the following types of use cases have been discussed in the consortium: drone as a first responder, drone for damage assessment, drone to assist hazmat incident, and lost person search. The overarching term used with emergency response is "situational awareness." On-the-ground observers have been found to be excellent at reporting an incident; however, in the heat of the moment, adrenaline sometimes clouds how they need to respond. Sending too many resources to an incident costs direct money for fuel and people, but also indirect costs of resources not being available for other possible simultaneous incidents.

Our initial focus will be on emergency response to a hazmat incident. Drones can play an important role to provide first responders with aerial views from the area where a hazmat incident has occurred, for increased situational awareness. One example might be a fuel truck involved in a highway accident that resulted in fuel spillage and/or a localized fire. In such a situation, drones could transmit high quality video as well as data from other sensors. Access to such data would help assess the severity of the incident and optimize resources to be dispatched at the scene. Drones can be deployed quickly and can arrive at the incident scene much faster than ground vehicles. Traffic on the highway may already be blocked or encountering heavy delays, slowing even the arrival of emergency vehicles on the scene. In addition, drones can be deployed much closer to the incident for an initial assessment, without further endangering people for this initial assessment.

Based on initial information from the surveying drone, additional drones could be deployed near the scene. The Remote Pilot in Command (RPIC) could also directly control its drone at the scene to get better views from different vantage points. The RPIC can be located nearby at a safe distance from the scene and perform a VLOS operation with the drone. Alternatively, the RPIC can be located at a command center, and perform a BVLOS operation. The sharing of live, high-quality video with multiple teams is invaluable to the response commanders.

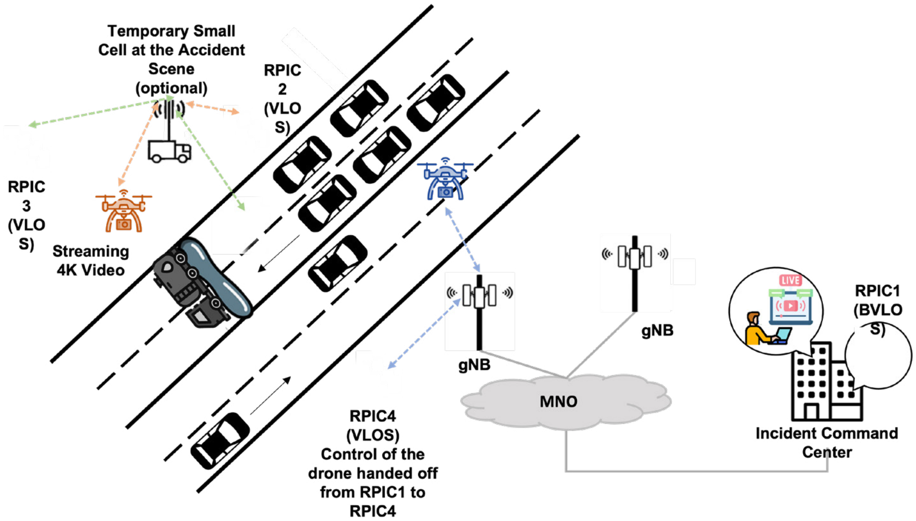

FIGURE 3. OVERVIEW OF EMERGENCY RESPONSE USE CASE

If the incident necessitates it, a temporary Non-Public Network (NPN) with one or more portable 5G cells could be placed in the area of the incident to provide connectivity for continuing to assess the situation locally and from the incident command center. The intent is to add capacity and improve coverage when needed.

The drones participating in this use case and the corresponding Ground Control Station GCS(s) are 5G-enabled. Drones need to establish and maintain connectivity with the RPIC so that the pilot can fly the drone (direct stick steering) at any time during the operation or for the entire operation. The drone is capable of using video to aid in its BVLOS operation as needed. Drones also need to be capable of flying pre-programmed flight routes, but an RPIC can still take over at any time. For this use case, the need to operate multiple drones within the area to respond to the emergency is envisioned. Initially, a scenario with up to three drones simultaneously operating within the area is considered.

Example operation

1. One or more drones, equipped with 5G connectivity are available for deployment at any given time to support emergency response operations. The remote pilot in command (RPIC) can command the drone using a ground control station (GCS), and also receives additional mission telemetry and video from the drone during the entire operation supporting the response to the hazmat incident.
2. One or more communications modes can be used:
   a. RPIC prepares the drone for the mission, performs pre-flight inspection, and identifies the drone flight path for quickly responding to the incident. The drone flies in a pre-programmed (or programmatic) manner.
   b. RPIC may control the drone in a pre-programmed manner (through waypoints) from take-off until the drone arrives close to the incident area, and at any time, it may control the drone directly (direct stick steering). If needed and equipped, the UAV can be brought to ground level close to the incident to "sniff" the air to better determine the toxicity level and nature of the spill.
3. While en-route to the incident location, the drone follows the pre-programmed route and flight altitude. A maximum flight altitude of 400 feet above ground level (AGL) is assumed for this use case. The drone may still receive updates to the route, from the RPIC as needed, during the operation.
4. The drone periodically reports its current position, velocity, battery condition, sensor outputs, heading, and time. The drone sends video or images such that users can see the broader aerial view while en route to the incident.
5. The drone may encounter obstacles (e.g., power lines or overpasses). The drone is capable of obstacle avoidance (e.g., it is equipped with acoustical or optical sensors).
6. Either while en route or at the incident location, the drone may encounter manned aircraft (e.g., a police/medical helicopter responding to the same incident). The drone is capable of deconflicting with manned aircraft (e.g., it is equipped with ADS-B).
7. Either while en route or at the incident location, the drone may encounter other drones from another organization/team responding to the same incident. The drone is capable of deconflicting with other drones (e.g., by being equipped with cooperative traffic sensors).
8. Once at incident location, the drone will send high quality video (4K and up to 8K) and other sensor data (e.g., air quality, thermal images) to be used by first responders in one or more locations.
9. Depending on the scenario, video transmitted by the drone can also be used by the RPIC to make changes to the drone's location within the incident area once initial information (video and sensor data) from the incident is received.
10. First responders may ask for deployment of additional drones to the incident location, after reviewing initial information transmitted by the drone.
11. RPICs can operate drones VLOS or BVLOS in support of the mission.
12. If necessary, depending on the expected duration for solving the incident, a temporary NPN network may be deployed at the incident location to facilitate the transmission of high-quality video and sensor data over

the duration of the incident, and to assess the progress towards resolving the incident. As an option, the temporary NPN network may also have internet connectivity.

13. If the drone operated in a pre-programmed manner, at the end of its specific mission, it must return to landing position, land safely, turn off its camera and/or video stream, and power off.
14. If the drone was directly controlled by RPIC, at the end of its specific mission, it will land per RPIC command.

Indoor Inspection and Security Use Case

Drones are used indoors to fly programmatically defined missions within warehouses and other large indoor spaces. The missions traverse pre-determined routes or visit waypoints to collect images in real-time and/or stream video for indoor inspections, warehouse inventory management, or indoor security, where a drone's ability to follow a path and provide real-time video uplink is central to the application. Missions may be started by schedule or on-demand. The drone is equipped with cellular

TABLE 3. COMMUNICATION REQUIREMENTS OF THE EMERGENCY RESPONSE USE CASE

	Direction	Throughput (kbps)	Round-Trip-Time (ms)	End-to-End one-way latency (ms)	Reliability (PER)	Priority
Command and Control (C2) *Waypoints-based*	Both	35	500		1e-5	Very High
Command and Control (C2) *Direct stick steering*	Both	35	100		1e-5	Very High
C2 Video *BVLOS pilot video* *720p to 1080p*	To GCS	4000-9000		140	1e-5	Very High
Detect and Avoid (DAA) *Drone-to-drone*	Broadcast	35		100	1e-5	Very High
Detect and Avoid (DAA) *Manned aircraft to drone*	Broadcast	35	1000		1e-6	Very High
Mission Payload* *Up to 4K or 8K Live video*	From Drone	Up to 25000 for 4k video Up to 50000 including other sensor data Up to 100000 in case of 8K video		100	1e-5	Very High
	To Drone	600		20	1e-5	Very High

Note (*): In support of the mission, the drone transmits up to 4K or 8K live video from the incident location, as well as other sensor data. The drone receives service control data from the ground based on needs to control different equipment on the drone (e.g., rotate payload camera, activate different sensors).

modems and uses an indoor NPN 5G network throughout the mission. The drone is equipped with collision avoidance systems to avoid hitting walls, equipment, furniture, people, or other installations in the building (e.g., sprinkler systems).

Example operation

1. The user defines missions with one or more waypoints that require photo or video inspection.
2. The user can access a dashboard via a web interface to dispatch a drone (from a set of one or more drones) to perform the inspection mission.
3. The dashboard is used to communicate with the drone's programmatic command and control system, and also to view the information collected during the inspection.
4. When the mission is started, the drone takes off and follows programmed mission waypoints. How the drone gets instructions is an architecture choice: the drone may contain enough map data to plot its own course, or it may get step by step movements from an off-board command and control system. 5G's bandwidth and low latency enable more architecture choices, which may be influenced by other platforms where the drone is part of a larger set of Industry 4.0 applications.

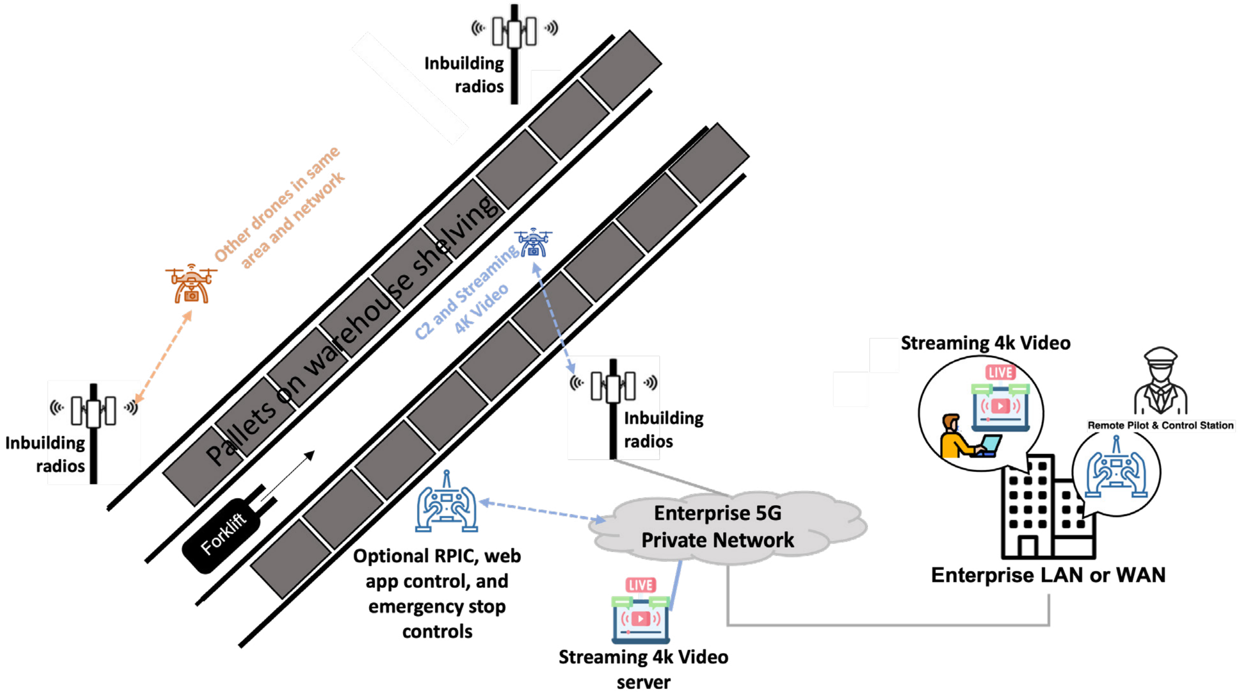

FIGURE 4. OVERVIEW OF INDOOR INSPECTION AND SECURITY USE CASE

5. In case of an emergency, the drone must be able to receive commands from local or remote operators, which can immediately interrupt the mission (e.g., stop and hover, land, return to home position, etc.).
6. For example, an emergency stop button may be positioned on the warehouse floor for workers to press and trigger a pre-programmed emergency procedure. When multiple drones are part of the same system, the system must determine which drone is affected based on factors such as location of the requesting person (e.g., stop button nearest to drone), or a remote drone operator must select which drone's mission to interrupt.
7. At end of mission, the drone must return to landing position, land safely, turn off its camera and/or video stream, and shut off and start self-charging.

TABLE 4. COMMUNICATION REQUIREMENTS OF THE INDOOR INSPECTION AND SECURITY USE CASE

	Direction	Throughput (kbps)	Round-Trip-Time (ms)	End-to-End one-way latency (ms)	Reliability (PER)	Priority
Command and Control (C2)	Both	35	500		1e-5	High
Mission Payload *4K video or photos*	To GCS or Other Server	25000		360	1e-3	Best effort
Map Updates	To Drone	100		100	1e-4	Medium

Summary

In this document, we have presented four use cases that form the basis of the initial work in the Open Generation consortium. These use cases have been identified as key examples of drone operations that can be enabled with the help of innovative 5G capabilities. With this initial description, and with identification of key challenges and requirements pertaining to each use case, the other workgroups in the Open Generation consortium (namely the Architecture & Solutions workgroup and the Implementation, Testbeds, & Experimentation workgroup) propose architectures that instantiate relevant components of the proposed scenarios, as well as the description of experiments to assess and validate performance.

The Architecture & Solutions workgroup has started reviewing and addressing Use Case–specific requirements and is proposing an architecture framework to support these use cases. Solutions for experimentations and simulations are being discussed at this time.

The Implementation, Testbeds, & Experimentation workgroup is currently working plans and detailing experiments based on the requirements identified by the Advanced Use Case and Devices workgroup; it has identified potential testbed locations and launched initiatives to perform experiments and simulation studies.

As MITRE’s tech foundation for public good, MITRE Engenuity collaborates with the private sector on challenges that demand public interest solutions, to include cybersecurity, infrastructure resilience, healthcare effectiveness, microelectronics, quantum sensing, and next generation communications.

For more information on the Open Generation consortium mission and progress of activities, please check our web page at: https://opengeneration.mitre-engenuity.org/

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