Sung, Ki Won; Sharma, Sachin; Destino, Giuseppe; Deng, Yansha; Mahmoodi, Toktam; Ullmann, Markus; Nahler, Achim; Kyung, Yeosun; Kim, Seunghwan; Seo, Sejin; Kim, Seong Lyun; Mutafungwa, Edward; Jantti, Riku; Choi, Minseok; Jeon, Joohyung; Kim, Dohyun; Kim, Joongheon; Costa-Requena, Jose; Nordlow, Anders

PriMO-5G: Making firefighting smarter with immersive videos through 5G

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Abstract— **In this paper, we introduce PriMO-5G which is an EU-Korea collaboration project studying the use of 5G technologies and unmanned aerial vehicles (UAVs) or drones to enhance the safety and efficiency of firefighting operations. We start by describing envisaged use cases of smart firefighting focusing on how the 5G communications with drones can help the firefighting. Inspired by the use cases, we identify several research challenges that call for new solutions in 5G radios and cores for mission-critical services. Then, a discussion of a new framework for defining key performance indicators (KPIs) follows. Finally, we introduce our effort and future plans for the demonstration of the technologies that the PriMO-5G develops.**

Keywords—firefighting, 5G, unmanned aerial vehicles, immersive video, use case, key performance indicator, demonstration, PriMO-5G

I. Introduction

Fires are a growing challenge for modern society, with increasing evidence of rapid urbanisation and climate change effects (e.g. global warming, shorter precipitation seasons etc.) fuelling both the scale and frequency of the occurrence of these fires [1]. These trends have even been observed in geographically northern countries with cooler climate histories. For instance, data gathered by the European Forest Fire Information System (EFFIS) indicates that Sweden experienced an almost fortyfold increase in the size of burnt areas in 2018 compared to annual averages of the preceding 10 years (see Fig.1) [2].

The increased scale and frequency of fire occurrences, together with the dynamic nature of fires, make firefighting operations increasingly complex, high risk, as well as, demanding in terms of required firefighting resources and technologies [3]. Typical firefighting operations may involve everything from prioritization of engagements, international agreements, protection of citizens, security of emergency areas, handling traffic situations, evacuations, communications, definition of areas for water acquisition, coordination with the military, to having the right supporting frameworks in place at the right time with the right performance.

The use of increasingly sophisticated public safety communications systems and aerial support systems is now critical for enhancing safety and efficiency of firefighting operations. Communications technologies that enable immersive services and reduce constraints on operational data sharing provide significant enhancements in situational awareness for emergency first responders and their effectiveness in managing hazards, such as, fires. To that end, the envisioned performance and architectural enhancements of the fifth generation (5G) mobile technologies have drawn significant attention from the public safety community [4], which has traditionally had to contend with performance limitations and inflexibilities in legacy commercial mobile networks and professional mobile radio (PMR) networks, e.g. terrestrial trunked radio (TETRA).

The PriMO-5G is an EU-Korea collaboration project studying the use of 5G communications technologies and unmanned aerial vehicles (UAVs) or drones for firefighting operations [5] [6]. For this, the PriMO-5G project has specified firefighting use cases that consider both forest fires (wildfires) and urban fires. These use cases take into account contextual differences between those two environments and envision how 5G-related technologies (e.g. network slicing, edge computing, etc.) could support firefighting operations both from the ground and from the air using drones, and effectively make the firefighting operations smarter. The overarching goal of PriMO-5G is to research and experimentally demonstrate end-to-end 5G systems providing immersive video services for moving objects. This will be achieved by the use of testbeds in Europe and Korea that integrate radio access and core networks innovations from different project partners.

The rest of this article is structured as follows. We present the PriMO-5G firefighting use cases in Section II, which in turn inspire the main research challenges in Section III that must be tackled for this smarter firefighting vision to be realised. The approach for specifying key performance indicators (KPIs) in this context is presented in Section IV. Demonstration efforts and future plans within the PriMO-5G project are introduced in Section V. Finally, we provide conclusive discussions and outlook in Section VI.
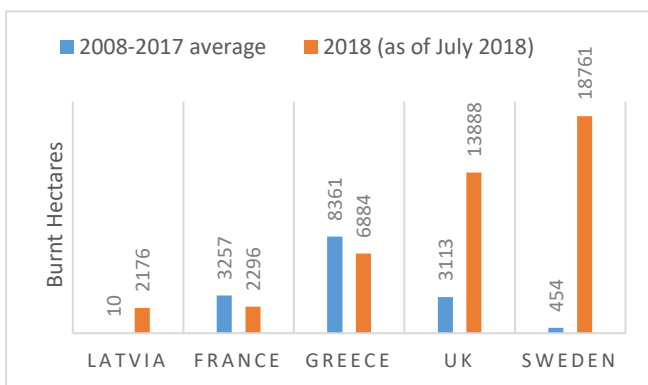

Fig. 1. Estimated burnt land hectares in selected European countries (data source: [2]).

II. PRIMO-5G USE CASES

Firefighting is a difficult and dangerous operation, and so there is a strong need for making firefighting smarter [7]. We envisage that the use of UAVs, particularly drones, will make the firefighting much safer and more efficient if it is combined with 5G communications. The usage of drones for firefighting can be divided into three categories as explained below.

The first category is preparatory actions. Drones can be dispatched to the fire scene faster than fire trucks to gather the overall situational information. In busy urban areas, drones can also be used for finding the optimal route and controlling traffic to ensure that the firefighting team reaches the scene as quickly as possible. Furthermore, the drones can interact with the people around the scene to evacuate them to the safe area.

Second, the drones can provide visual information to firefighters and the incident commander. The use of immersive video services, i.e. virtual reality (VR) and augmented reality (AR) is a key to this enhancement. The visibility of fire scenes are usually limited due to obstacles, debris, and smokes. To overcome the lack of sight, a fleet of drones can make a real-time wide-angle VR video from the sky so that the incident commander has a proper awareness to the situation. For firefighters, seen-through-the-obstacle visibility enhancement can be provided with the help of AR devices.

Third, the drones can gather sensory and measurement information of the fire scene and surroundings and report it to the firefighters and the incident commander. This will help the firefighters locate the people to rescue, identify toxic substances, and detect the possible explosion or collapse. Thus, the safety of firefighting crew can be enhanced significantly.

Firefighting in urban and rural areas have both similarities and differences with regard to the requirements for communications. The commonalities and the distinct characteristics are described below.

A. Urban firefighting

A crucial aspect of an urban setting that we have to account for is its density, i.e. population, network nodes, and traffic. Concentrated population around the site, both victims and passersby, further intensifies the threat of a fire accident and increases the complexity of countermeasures that have to be taken. In addition, traffic congestion of automobiles makes it difficult for the fire engines to arrive before the critical time, commonly known as the "golden time" of the operation. Finally, diverse and abundant network nodes, which aid us in our normal lives, could hinder the operation at its critical moment. Nevertheless, we consider this setting advantageous for our proposed scenario. We take the urban environment as an adequate setting for a more sophisticated and versatile smart firefighting operation by fully utilizing two key enablers for our scenario: drones and 5G networks as depicted in Fig. 2. Utilization of existing mobile network infrastructure and network slicing are among the foremost requirements.

B. Rural and forest firefighting

Contrary to the urban case, the lack of existing infrastructure is a challenge to overcome. It is possible that the fire area is out of the reach of existing mobile network except for traditional voice and low data rate services. In this case, fast deployment and setup of communications between the firefighters, incident commander, drones, and control center is
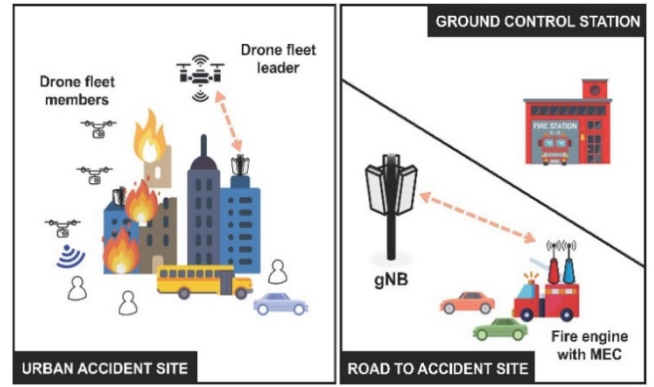

Fig. 2. An illustration of smart firefighting in urban scenario.

a key requirement for the smart firefighting operations. Radio spectrum access and backhauling to command center constitute distinct challenges for the rural case.

C. Requirements for firefighting communication systems

Communication systems for smart firefighting, both in urban and rural areas, have the following requirements.

1. Connectivity: main actors of the scenario – the drones, fire engines, and the fire station (ground control station) – are all connected with each other. This enables direct and efficient communication of control and sensory signals that are critical to the mission.

2. Low latency: real-time streaming of high-quality media from the drones opens up the possibility for immersive and immediate awareness of the situation from a distance.

3. Reliability and capacity: increased reliability and capacity allows different heavily loaded pipes of information, i.e. data collected by drones and resources for machine learning, to be communicated simultaneously.

Additionally, the overall system is divided into different tiers, according to the resources the actor possesses. By this division and adequate allocation, we are expecting to boost the utilization of different computing and communicating resources the overall system possesses. The overarching layout for this scheme is explained further in Section V.

III. RESEARCH CHALLENGES

In the context of two separate scenarios of remote and urban areas, the PriMO-5G project identified several research challenges, necessitating advancements in the whole arena of 5G communications systems and, more specifically, in the development of new solutions for aerial-terrestrial networks. In fact, the PriMO-5G project tackles several critical challenges of UAV networks, which directly call for new solutions in 5G radios and cores for mission-critical services in the following.

A. Maintaining reliable high data-rate link in a dynamic environment

The first challenge is how to ensure the fast-changing communication link quality and availability due to dynamic and unpredicted alternating of line-of-sight (LOS) and none-line-of-sight (NLOS) channel conditions as well as mobility of both users and radio access nodes (moving gNB). New enablers are sought with the application of artificial

intelligence (AI) for beam-management, beamforming prediction, cell-free architecture, multi-connectivity, and duplex communications.

B. Trade-offs between communication latency and computing power

The second challenge calls for new multi-access edge computing (MEC) functionalities tackling the trade-offs between communication latency (or data rate) and computing power. To exemplify, consider the use-case scenario for urban fighting where a two-tier network is constructed including the incident commander, the fleet leaders, and the fleet members. The computing capacity and their power resources of each entity are different. On the one hand, if the fleet members process the collected images and deliver those to firefighters at the incidental site, then latency would be very small but power consumptions for image processing could be critical for battery-powered drones. On the other hand, the incident commander has a much larger power budget and better computing capability than the drones, so it could easily process the received images, but large communication latency and load are anticipated.

Therefore, the dynamic decision policy to assign the image (or any power-hungry) processing task is required. In order to support low-latency applications in a scenario where all nodes are moving, it is important to develop handover and service placement strategies that follow the network dynamics. In this regard, a service migration function must be supported at the MEC along with efficient network slicing and reconfiguration.

C. Provisioning live, high-quality and reliable video streaming

In a fire disaster, visual information can be exploited in various manners. Firstly, live streaming of the incident site can help an incident commander who is an expert in fire disaster but located far from the site. This is possible with low latency wireless communication. Secondly, high-quality and reliably streamed video can be utilized as the input of various image processing and video analysis algorithms at the server site with high computing power. Through the analysis, disaster action manual can be established and prioritized to minimize the property damage as well as damages inflicted on people on site. For this purpose, it is essential to receive reliable visual information with high quality. As a result, there is a bottleneck in wireless communication to support both streams with different requirements at the same time. Therefore, further research on the design and optimization of the transmission system should be conducted.

D. Network Slicing

The mobile backhaul is based on best effort IP networks which have been over-dimensioned for handling the expected traffic demands. However, 5G networks is envisioned for not only customer services but machine-type communications. 5G mobile networks aim at new features like ultra-reliable and low-latency communications (URLLC). Network slicing allows operators to share a single mobile network with different requirements. The operator can reserve some of the available resources for pre-configured network slices to guarantee URLLC type of communications to selected customers. However, pre-provisioning cannot work in 5G networks to ensure URLLC services since the set of assigned resources can be increased and decreased in size based on user needs and policies that change over time. Therefore, the current practice of the pre-configured radio interface which is then mapped statically into differentiated services code point (DSCP) traffic marking in mobile networks is not sufficient for 5G. The network slicing allows the classification, isolation, and prioritization of real-time information to be used for different types of critical communication. Specifically, network slicing in the firefighting scenarios requires a dynamic and effective deployment to support several traffic types for various purposes: drone control, collision avoidance, services (e.g. video), public safety functions (e.g. police, medical), and public safety management (strategic, tactical, operational).

E. Radio Spectrum Access

In the rural use case, forest firefighting does not happen every day, and so it would be a waste of valuable spectrum resources to allocate dedicated spectrum for the firefighting communications. However, there must be a clear rule or arrangement on the frequency band and authorization scheme so that the communications become available at the fire scene as quickly as possible. A quick and temporary spectrum leasing from mobile network operators (MNOs) for the case of emergency can be an option. Feasibility of using license-exempt spectrum can also be studied.

F. Dynamic Fleet Control and Task Type Assignment

Drones take at least one of the main roles as follows: 1) real-time image collection, 2) sensory information collection, and 3) monitoring and interacting with the surrounding environments, e.g., vehicular traffic. Depending on the location, the information from a certain type of sensor would be better for the drones to collect than the information from the other types. For example, the sensory information could be collected accurately as the drone is located close to the fire scene. On the other hand, it is important to observe the visual information at various angles at a distance from the fire scene. In this case, not only task type assignments but also dynamic control of locations of the drones is important.

G. Location Awareness

Location-awareness (node location and map information) is a key for service and radio resource optimization. This can be achieved via 5G radio-link based measurements as well as integration with the global navigation satellite system (GNSS). Different implementation can be considered including centralized (in the network) and distributed (local at each node). Additionally, locations and battery charges of the drones are necessary for dynamic fleet control and radio resource optimization. The incident commander should receive all information regarding drone locations and battery charges; and high reliability is required for all those links.

H. AI Assistance

1) AI-assisted image processing: drones located at the incidental site are in very harsh environments, and they are usually battery-powered. Therefore, it is difficult to collect the high-definition images owing to power efficiency and very high temperature from the fire scene. In this case, AI-assisted enhancement of image quality can be considered to obtain the high-definition real-time images of the incidental site.

2) AI-assisted path control: the real-time images should be collected at various angles and distances to provide the
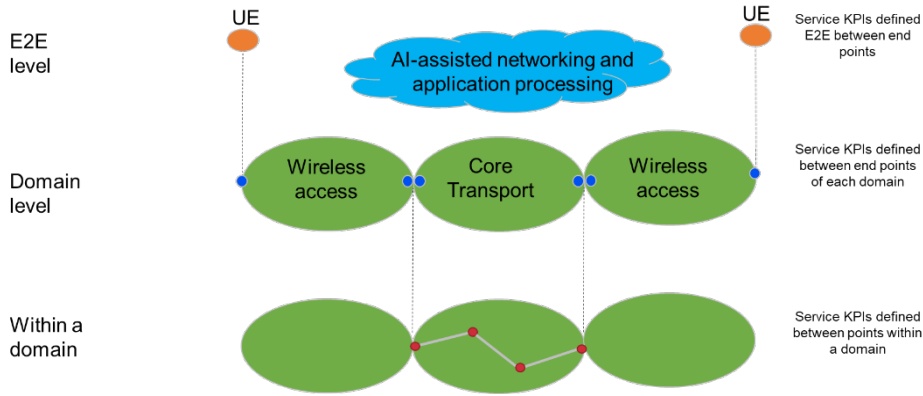
Fig. 3. Hierarchical framework of defining KPIs.

appropriate instructions to firefighters at the incidental site. For this goal, the incident commander needs to control the locations of the drones. Also, since there are many blockages in the fire scene, the drones should find a better LOS channel to provide a clearer visual information. Especially when mmWave network is used, high reliability relies on finding the path of acceptable link quality. Therefore, the drones need techniques to detect its pathway based on learning methods and to move to find the LOS channels.

IV. PERSPECTIVES ON KPIS

The evolution from 4G to 5G added much more flexibility and reconfigurability to the standard than in any mobile communications standard before. Examples are network slicing, orchestration and optimization through AI-assisted algorithms. These new prospects imply new approaches for defining key performance indicators. We present a hierarchical KPI framework which divides the view on KPIs from end-to-end (E2E) level down to domain specific levels.

The traditional way of designing services has been to consider static requirements of services as a part of network planning. Once all requirements are known a priori, a network design can be rolled out to fulfill these requirements. Within a 5G network services can be introduced dynamically into the network. This needs to be supported by highly advanced management and orchestration solutions.

The general approach of the KPI framework in the PriMO-5G project is that the KPIs are hierarchically defined. The first step is to define E2E service KPIs for the service instance introduced by the use cases. The second step is to break down the E2E service KPIs to KPIs per domain. The third level is to break down KPIs within the domain. For a core transport level, this could mean that it is done per link. The management and orchestration layer, as well as the different functions on the domain level, can support a highly automated approach of the service introduction. Fig. 3 depicts the concept of hierarchical KPI framework.

E2E KPIs are heavily affected by the deployed computing algorithms and the computing power of the nodes in the E2E system. Exemplarily for a real-time video service, the resolution and frame rate would be the key requirements of the application, and traditionally these have been directly translated into the data rate, which is one of the typical E2E KPIs. However, the introduction of computing solutions, particularly AI-assisted networking and application processing algorithms, can lower the data rate requirement for the same perceived video quality. On the other hand, such computing and application processing solutions will contribute to the latency, which could make the E2E latency requirement tighter. Therefore, proper E2E service provisioning needs to take both computing and E2E communications into account.

E2E KPIs for the PriMO-5G use cases are:

- Data rate
- E2E latency
- E2E reliability
- Service deployment time
- Security
- Operational deployment time
- Operation durability
- Position accuracy

3GPP defines a QoS framework that supports KPI compliance. The QoS framework covers both the radio access network (RAN) and the 5G core network by introducing QoS flows. Quality-of-Service (QoS) flows are classified in predefined sets of properties. 5G QoS indicator (5QI) values identify these classified flows [8].

The 5G network supports different types of data like eMBB, URLLC or mMTC. Networks slicing is used to separate the different data types and QoS flows from each other. The networks slicing is enhanced by machine learning algorithms to dynamically orchestrate the software defined networking (SDN) based core network. The high-grade configurability of 5G requires an iterative design process to keep up with the changing requirements of running services.

V. DEMONSTRATION AND TESTBED

A. 5G OPEN Event

The PriMO-5G team held "5G OPEN" event in December 2018, where the team members presented the project goals and future plans, and demonstrated some of the results. In this subsection, the initial demonstration results shown at the "5G OPEN" are described, which is based on the network setting illustrated in Fig. 4. In the demonstration, drones were located in the incident site (Incheon, South Korea) and the depth-controllable super-resolution (SR) technique [9] was utilized at the server located in Seoul. Network infrastructure including 5G gNB (3.5 GHz) was installed and coordinated by Korea Telecom (KT), Eucast, and Yonsei University. On site, an Intel Aero-RTF drone was used to maneuver and report the incident status by streaming live video feeds while KT Skyship was hovering above the site to coordinate the overall
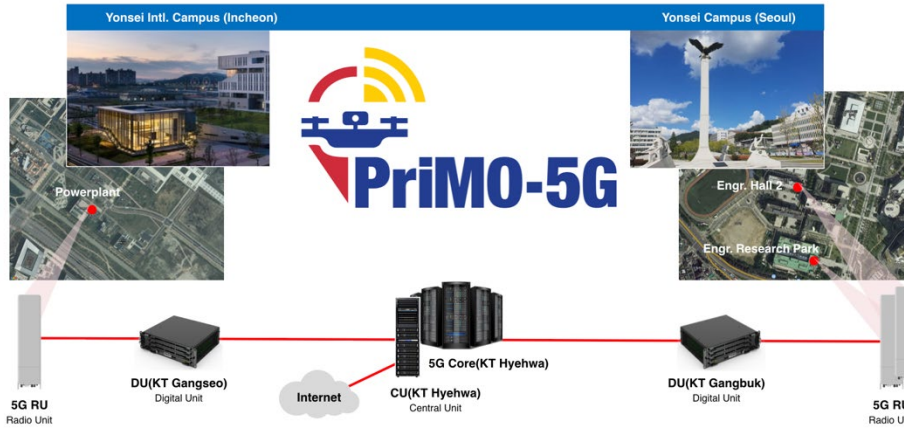
Fig. 4. 5G OPEN event network setting.

situation. C920 camera and antennas were added onto Intel Aero-RTF for better image quality and extended coverage. The SR technique controls the number of the depths of the neural network for SR imaging, and therefore can dynamically adjust the trade-off between the output image quality and the computational tasks. The depth-controllable SR technique is advantageous for drones to support emergency tasks in the disaster scene.

Before installing the instruments for SR imaging on moving vehicles or drones, the depth-controllable very deep SR (DCVDSR) network was tested on the static command center. In the demonstration, a drone collected the real-time images and transmitted them to the center, and the command center improved the image quality by using DCVDSR. For SR imaging based on DCVDSR framework in [9], CPU of Intel i5-8400 (2.8GHz) and GPU of NVIDIA GTX 1060 3GB were used, respectively. In addition, the processing computer was equipped with the RAM of DDR4 16GB and the storage of SSD memory 128 GB. The operating system was Ubuntu 16.04, and GStreamer was used. Images with the original resolution of 640x480 were compressed at the transmitter with the factor of 60 times, and with the frame per second (FPS) of 30. For training of the deep neural network, we applied the data augmentation with scaled (by x2, x3, and x4) images.

We conducted a qualitative evaluation of the DCVDSR with the following considerations: 1) whether the proposed model has a visually plausible ability to upscale low-

Fig. 5. Results of qualitative evaluation of DCVDSR.

resolution images, and 2) whether the proposed model possesses trade-off factor, i.e., its visual quality is improved progressively as the depth of layers becomes deeper.

We performed up-scaling using a different branch of usable depth set for patches of the received image. We first obtained the low-resolution images with a scaling factor 3 from the original image, and then we upscaled it using DCVDSR with the corresponding scaling factor. As shown in Fig. 5, the output branch at the shallowest depth performs significantly better than the bicubic interpolation, and the quality gradually improves as the layer becomes deeper. The improvement is distinct from that in the shallow layer; however, as the layer becomes deeper, the difference can be compromised according to the purpose.

B. Future Demonstration Plans

In the previous demonstration, we considered only one-to-one communication between a drone and the command center that controls computation tasks of SR imaging depending on the channel condition. To reflect the practical characteristic of the use cases in this project, three important points of improvement are necessary:

1) DCVDSR at moving vehicles or drones as well as at the command center,

2) 5G backhaul connections for transmitting the real-time images, and

3) two-tier hierarchy and communication loads between different tiers.

4) NLOS control of drones over 5G radio access and core networks with low latency.

The hierarchical edge computing system is described in Fig. 6. Drone members collect the real-time images and transmit them to their drone commanders and/or the MEC server directly, and drone commanders transmit the gathered information to the MEC server. Similarly, transmissions of instructions downwards from the MEC server to drone members are made. The key of this hierarchical division is to fully utilize the different resources that are constrained to certain specifications. Accordingly, drone fleet commanders will execute actions that require high computing and transmitting capabilities. Nonetheless, fleet members do not act merely as passive nodes to aid the leaders: they will execute active small-scale missions on site, e.g. showing evacuation paths and sending out evacuation signals.
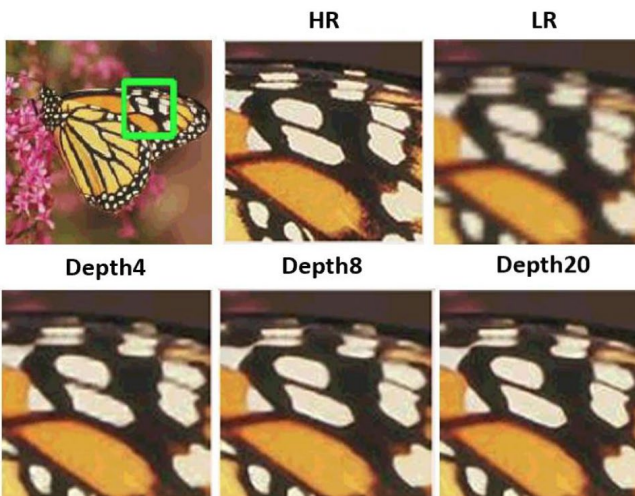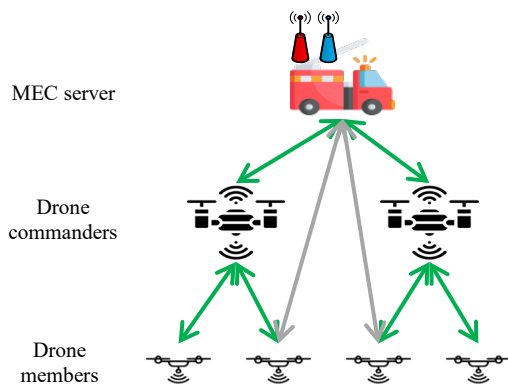
MEC server

Drone commanders

Drone members

Fig. 6. Two-tier hierarchical system.

Furthermore, communication links from the lower tier to the higher tier will require high data rates and very fast delivery of the necessary information. However, the channel condition near the disaster scene is expected to be very harsh and resources should be distributed to many drones. Therefore, drone members would prefer to transmit the compressed version of the collected images. However, the more compressed the images received by the drone commander are, the more computational work is required to improve the image quality. The channel capacities (for drone-to-drone, drone-to-ground links), computation capabilities of all drones and the MEC server, and the hierarchical structure will influence decisions on:

- How much compression is applied to the collected images,

- Which tier processes the compressed images,

- How to organize the hierarchy and how to group drone fleets.

Therefore, the next demonstration will show how to dynamically control the tradeoff between communication and computation loads among different tiers. Furthermore, the demonstration will provide a means for investigating how the hierarchical architecture and drone groupings impact this computation versus communication trade-off.

VI. Concluding Remarks

Fires are a growing challenge for the modern society. The use of sophisticated public safety communications systems and aerial support systems is now critical for enhancing safety and efficiency of firefighting operations. The PriMO-5G project is an EU-Korea collaboration project studying the use of 5G communications technologies and UAVs, particularly drones, for firefighting operations.

The use cases envisaged by PriMO-5G call for solutions in 5G radios and cores which accommodate both high data rate video traffic and URLLC control messages in a single network. Furthermore, the services should be provided through fast-moving drones with varying channel conditions. Therefore, dynamic beam management and network slicing are of importance. Location awareness and control of drone fleets are also challenging issues where AI-assisted algorithms are promising. It is important to strike a balance between communication latency and computing power in the use of AI-assisted algorithms and video processing techniques. Flexible and reconfigurable 5G requires a new framework of defining KPIs, which necessitate a hierarchical approach to KPIs.

The overarching goal of PriMO-5G is to research and experimentally demonstrate end-to-end 5G systems providing immersive video services for moving objects. The outcome of the project will contribute to making the firefighting safer and more efficient in particular, and enabling mission-critical services in general.

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