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D1.1 - PRIMO-5G USE CASE SCENARIOS

Work Package	WP1, Scenarios, architecture, economic and regulatory analysis
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Executive Summary

The main aim of the PriMO-5G project is to demonstrate an end-to-end 5G system providing immersive video services for moving objects. For this, work package 1 of the project strives to define and select scenarios and use cases capturing and stressing the main challenges. This deliverable presents a description of selected scenarios and use cases. It also presents a high-level framework of defining key performance indicators (KPIs).

Firefighting is an area where immersive video services with moving objects, particularly unmanned aerial vehicles (UAVs), can make a substantial improvement in the safety and efficiency of the operations, and therefore this deliverable focuses on the firefighting in the development of scenarios and use cases. Section 2 of this deliverable clarifies the definitions of the terminology related with the scenario work and system design, and specifies a scenario-based system design process that the project will adopt. Then, in Section 3, an overview of requirements and components for public safety communication systems for fire situations is provided. Inspired by the overview of Section 3, scenarios and use cases are introduced in Section 4. Two scenarios are introduced, each of which has two use cases. The scenarios are selected to reflect different environmental situations and associated requirements; scenario A considers a fire in rural areas, e.g. forest fire, where mobile network infrastructure would be only partially available and no other radio spectrum usage is expected; and scenario B is concerned with urban areas where dense but traffic-heavy mobile infrastructure exists and the firefighting operations could be severely affected by other people and cars near the fire scene. While the scenarios focus on the interactions between the actors of firefighting in these areas, the subsequent use cases reprise the scenarios from the functional and technical perspectives. The description of scenarios and use cases is followed by Section 5 which presents a high-level framework of service-oriented KPIs. It is emphasized that the KPI design in 5G can be a highly dynamic process with the advent of network slicing and orchestration. An end-to-end (E2E) KPI can be divided into domain-level KPIs, and then further into specific KPIs within a domain. AI-assisted networking and application processing algorithms that can be augmented in various steps of E2E services make the processing defining KPIs more dynamic. Section 5 shows a list of KPIs and explains how to define KPIs in each domain.

This deliverable will work as conceptual guidelines to the research in technical work packages, i.e. WP2-5, as well as regulatory and economic studies, i.e. Task 1.3 of WP1, of the project. The demonstration scenario in WP5 will be based on the outcome of this deliverable.

List of Acronyms

Acronym	Definition
3GPP	Third Generation Partnership Project
5G	Fifth-Generation Mobile Network
5GC	5G Core Network
5G-PPP	5G Public-Private Partnership
5QI	5G QoS Indicator
AI	Artificial Intelligence
AN	Access Network
AR	Augmented Reality
BE	Best Effort
BS	Base Station
DiffServ	Differentiated Service
DRB	Data Radio Bearer
DRX	Discontinuous Reception
DSCP	Differentiated Services Code Point
E2E	End to End
EMTEL	ETSI Special Committee on Emergency Telecommunications
eNB	Evolved Node B
ETSI	European Telecommunications Standards Institute
FFT	Fast Fourier Transform
gNB	Next Generation Node B
GBR	Guaranteed Bit Rate
GPS	Global Positioning System
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IITP	Institute for Information & communications Technology Promotion
IMT	International Mobile Telecommunications
IntServ	Integrated Service
IoT	Internet of Things

Acronym	Definition
IP	Internet Protocol
ISO	International Organization for Standardization
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LMR	Land Mobile Radio
LOS	Line of Sight
M2M	Machine-to-Machine
MEC	Multi-access Edge Computing
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
MNO	Mobile Network Operator
MPLS	Multiprotocol Label Switching
NB	Node B (base station)
NG-RAN	Next Generation Radio Access Network
NG-U	User plane interface between NG-RAN and 5GC
NR	New Radio
PDU	Protocol Data Unit
PHB	Per-Hop Behaviour
PLMN	Public Land Mobile Network
PMR	Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
PSAP	Public Safety Answering Points
PSC	Public Safety Communications
QFI	QoS Flow ID
QoS	Quality of Service
RAN	Radio Access Network
SDN	Software Defined Networking
SDU	Service Data Unit
TCP	Transmission Control Protocol
ToS	Type of Service

Acronym	**Definition**
TRxP	Transmission Reception Point
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UNISDR	United Nations Office for Disaster Risk Reduction
UPF	User Plain Function
URLLC	Ultra-Reliable Low Latency Communications
VLAN	Virtual Local Area Network
V2X	Vehicle-to-Everything Communications
VR	Virtual Reality
WP	Work Package

1 Introduction

1.1 Purpose and Scope

The main aim of the PriMO-5G project is to demonstrate an end-to-end 5G system providing immersive video services for moving objects. For this, we aim to define and select scenarios and use cases capturing and stressing the main challenges. As a first step, this deliverable defines the terminology related with the scenario work and system design, and specifies a scenario-based system design process that the project will adopt.

We consider firefighting to be an area where immersive video services with UAVs can bring about significant improvement, and therefore focus on the firefighting in the development of scenarios and use cases. Starting from the overview of requirements and components of firefighting communication systems, a description of scenarios and use cases is introduced. It is followed by a list of relevant KPIs and a high-level framework of service-oriented dynamic KPI design.

1.2 Structure of the document

This deliverable is organized as follows. Section 2 presents the definition of terminology related to scenario work and specifies a scenario-based system design process. Section 3 provides on overview of the requirements and components for firefighting communication systems. The PriMO-5G scenarios and use cases are described in Section 4. Then, in Section 5, methodology for defining KPIs is discussed and the KPIs that are relevant to the use cases are listed. Finally, Section 6 provides concluding remarks.

1.3 Relationship to other project outcomes

This deliverable will work as guidelines to the research of technical work packages, i.e. WP2-5 and the regulatory and economic studies in Task 1.3 of WP1. The system design process defined in this deliverable will be the methodology that the project will follow in the research of system architecture. The outcome of this deliverable will also serve as a starting point of demonstration scenarios in WP5.

2 System Design Process

This deliverable reports on the definition and selection of the main scenarios that will capture and emphasise the main challenges addressed by the PriMO-5G project, as part of the overall PriMO-5G scenario-based system design process. To that end, the identification and selection of scenarios, use cases and associated requirements is one of the main objectives of WP1 of PriMO-5G. This section provides the definition of terminology with regard to the scenario-based system design. Then, the overall process of system design is illustrated which includes the interdependency between the work packages of the project. Finally, methodologies for specifying PriMO-5G scenarios and use cases are introduced.

2.1 Definition of Terminology

Architecture (of a system): Set of rules to define the structure of a system and the interrelationships between its parts (ISO/IEC 10746-2).[1] The architecture provides means for describing the elements and interactions of a complete system including its hardware elements and its software elements.

Requirement: A function, constraint or other property that the system must provide (or may optionally provide if requirement is not mandatory) to fulfil the needs of the system's intended users.[2] Scenarios are usually defined in connection to user requirements specification, and they are refined to use cases during the functional requirements definition phase. It is quite common that a long scenario may be split into several use cases.

Scenario: Usage scenarios are stories that describe how users will interact with the system to accomplish particular goals or tasks.[3] Other definitions:

- A wide application area, where the proposed technology can be valuable. A scenario describes the environment in which a set of use cases can be defined. Thus, it describes the complete functionality of the system and may include multiple use cases, following to certain assessment and/or criteria. (as defined in 5G-ESSENCE project[4])

System: A system is something of interest as a whole or as comprised of parts. Therefore, a system may be referred to as an entity. Furthermore, a component of a system may itself be a system, in which case it is referred to as a subsystem.[5]

System requirements: encompass all functional and non-functional aspects that need to be factored in order to reflect the user requirements on the system design. System requirements are further classified as:

- **Functional requirements**: define specific system behaviour or functions (e.g. slicing)
- **Non-functional requirements**: provide criteria that can be utilised for judging the operation of the system. Related to system properties such as performance, reliability, availability, reconfigurability, usability, security and so on.

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[1] ISO/IEC 10746-2 Information technology -- Open distributed processing -- Reference model: Foundations, 2009. https://www.iso.org/standard/55723.html

[2] R. Abbott, An Integrated Approach to Software Development, John Wiley, New York, 1986.

[3] M. Rosson and J. Carroll, Scenario-Based Design. In: J. Jacko and A. Sears, editors. The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications. Lawrence Erlbaum Associates, 2002. pp. 1032-50.

[4] Horizon 2020 Project 5G-ESSNCE, http://www.5g-essence-h2020.eu/

[5] See footnote 1

Use case: A description of sequences of actions that a system or sub-system must perform during its interaction with the user(s).[6] It has previously been noted that use cases help to identify and clarify the functional requirements of the system to be designed whereas scenarios focus on identifying user and contextual requirements. Scenarios tend to describe actions on a higher level, rather than focus on details of actions/responses like use cases.[7] Other definitions:

- A specific application paradigm. A use case describes how the proposed technology can be used to “satisfy” specific needs, as can be defined per case. The use case is actually a sort of a “single path” through a diagram and focuses on a “piece of functionality” in a system. (5G-ESSENCE)

User: The person(s) or other entities that interacts directly with the system.[8] Other definitions:

- User or a stakeholder is a party, which is involved and affected by a specific scenario or use case. A stakeholder can take multiple roles. (5G-ESSENCE)

User requirements: Are requirements that tell what the system shall do from user’s point of view. These include aspects that users of the system expect to see reflected in the system. Specifically, it refers only to functions and properties visible to the users, whereas the system is seen as a black box

2.2 System Design Process

The PriMO-5G system is designed in a way that allows for iterations so as to take into account any evolving user and system requirements as well as the ongoing 5G technological progress, regulatory decisions and/or innovations (e.g. on 5G spectrum bands), prevailing 5G market trends and developments in 5G standards. The flexibility to absorb such changes requires a dynamic architecture design that cannot be captured in a linear design process with no feedback.

To that end, the design of the PriMO-5G system from scenarios to system architecture is loosely based on a well-established design process[9] that includes two main phases, the analysis phase which designs the framing conditions for the system architecture design and the actual architecture design phase. Figure 2-1: illustrates the iterative processes across the analysis and design phases and their linkages to the PriMO-5G work plan.

[6] I. Jacobson, M. Christersson, P. Jonsson, and G. Overgaard, Object-oriented software engineering: A use-case driven approach. Reading, MA: Addison-Wesley, 1992.

[7] R. Gonzalez, E. Kaasinen, T. Tuomisto, P. Valkkynen, and I. Jantunen, Usage scenarios Part II: generalized scenarios. FP6 MINAmI deliverable. 2008.

[8] IEEE Recommended Practice for Software Requirements Specifications, IEEE Std 830-1993, the Institute of Electrical and Electronics Engineers, New York, 1994

[9] FP6 ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management), “Reference model for the ORCHESTRA architecture,” Tech. Rep., 2007.

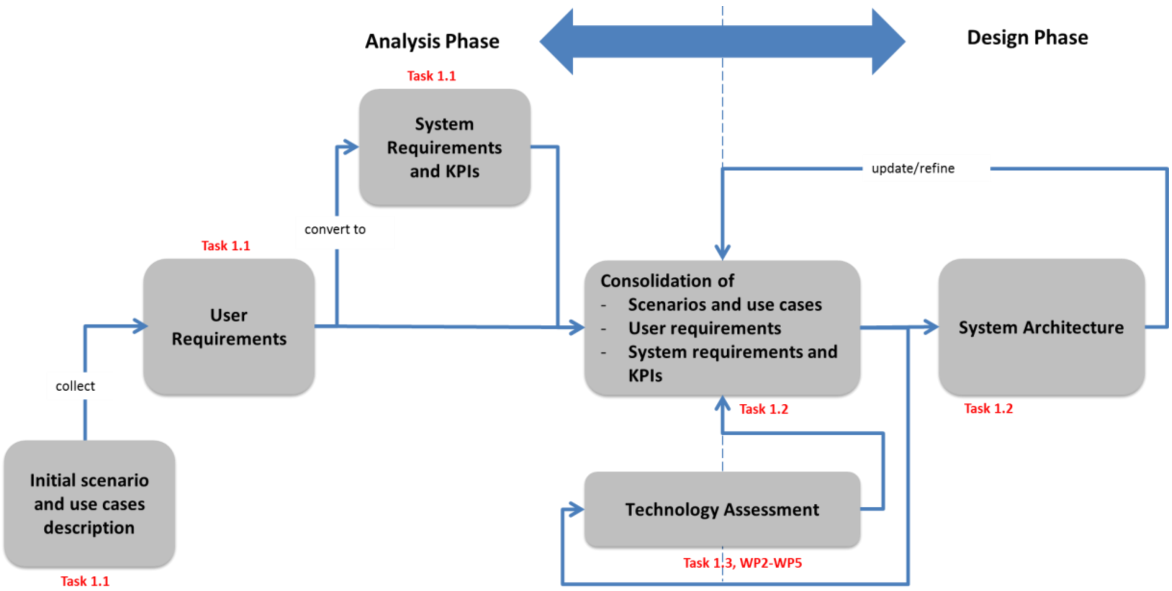

Figure 2-1: PriMO-5G system design processes

The PriMO-5G *scenarios* and subsequent *use cases* will be built on commonly occurring events or operations that may have value to users being virtually present in a particular location or environment.

The *user requirements* for the PriMO-5G system incorporate all expectations of the user on the envisioned PriMO-5G system in view of the context and needs of particular scenarios. The collection and refinement of the PriMO-5G user requirements is done from within the project (WP1) and through consultations with external stakeholders experienced in specific scenarios.

The PriMO-5G *system requirements* encompass all functional and non-functional aspects that need to be factored in order to reflect the user requirements on the system architecture design. A mapping of the user to system requirements is presented in the subsequent sections.

The *technology assessment* process is also an iterative process, by means of which it ensures that the PriMO-5G system requirements can be fulfilled with the currently available 5G technology, as well as, feasibility of implementations of demonstrations and validations within the consortium (in relation to WP5). Moreover, this process allows for assessment and incorporation of emerging developments from 5G standards and new research results conducted by the WP2 to WP4.

The consolidation process sits in-between the analysis and design phases. To that end, it ensures that, at a given point in time, there is a common understanding of the user requirements, the system requirements, and an assessment of the current technology as a foundation to design the PriMO-5G system architecture (to be specified in deliverable *D1.2 End-to-end PriMO-5G network architecture* due in June 2020).

2.3 Specification Methodologies

The PriMO-5G use cases and requirements documented in this report are expressed in structured natural language which provides a compromise between unstructured natural language (informal or narrative descriptions) that are easily understandable to the general reader and formal specifications or graphical notation that is usually preferred by system designers. This section provides some description of the conventions and methodologies adopted for specifying PriMO-5G scenarios and use cases and requirements.

2.3.1 Approach for Specifying Scenarios and Use Cases

For the specification of each scenario and subsequent use case, we consider the following aspects:

- Overall description;
- Actors involved;
- Preconditions;
- Identified requirements.

The aspects are elaborated further below.

Overall description:

It is a brief narrative description of the use case (about 0.5-1 page of text), preferably accompanied by simple illustration(s) of the use case. This description is written in a way that addresses the following questions[10]:

- What are you trying to do in the use case?
- How is it done today, and what are the limits of current practice? Why is it not good enough?
- What's new in the approach?
- Why is it needed (what are the addressed needs)? If successful, what difference will it make?

In the description the technical details and jargon should be minimal to ensure that it is understandable to all relevant stakeholders.

Actors involved:

This lists the different actors involved in the use case[11]. This includes end users or stakeholders that call on the system to fulfil their primary routines (e.g. firefighters). Specifically, these actors have a goal with respect to the system – one that can be satisfied by its operation, and are often the actors who triggers the use case. Actors can also be entities or stakeholders the system needs assistance from to achieve the other actors' goals (e.g. spectrum owners making their radio resources available for rapidly deployable firefighting networks etc.).

Preconditions:

A precondition is the state of the system and its surroundings that are required before the use case can be started. An example might be availability of spectrum band that can be assigned and reserved for system in executing the use case.

Identified requirements:

A list of preliminary requirements identified for the use case. These will contribute to the definition of the overall PriMO-5G system requirements.

[10] Loosely based on the Heilmeier questions https://www.darpa.mil/work-with-us/heilmeier-catechism

[11] A. Cockburn, Writing Effective Use Cases, 12th Printing, November 2004.

3 Background of firefighting communication systems

Firefighting is an area where immersive video services with moving objects, e.g. drones, can make the operations safer and more efficient. Therefore, the PriMO-5G project focuses on the firefighting in the development of scenarios and use cases. This section provides an overview of requirements for firefighting operations, and identifies necessary components of communication systems for firefighting.

3.1 Background on public safety communications

Emergencies are unfortunate but commonly occurring scenarios in most inhabited environments. These scenarios may range from rare but high-impact hazard events due natural phenomena (e.g., hurricanes, flooding) and deliberate or accidental human actions (e.g., forest fires, terrorist incidents), to small-scale but frequent emergency events (e.g., medical emergencies, road accidents). In all these scenarios, emergencies result in heightened risk to human wellbeing, life and/or property.

Regardless of the emergency type, the use of communications technologies and services is essential for mitigation and preparedness actions prior to an emergency event, as well as, immediate emergency response and long-term recovery operations after occurrence of the emergency event. To that end, the general term Public Safety Communications (PSC)[12] is loosely used to describe the utilisation of communications solutions enhancing the interaction between (and among) citizens and authorities for improved situational awareness, rapid response and cooperation across domains, so as to reduce the risk and minimize the impact associated with a particular emergency event. The term 'authorities' in this context collectively refers to emergency first responders (fire-fighters, police, paramedics etc.), emergency control centres, public safety answering points (PSAP), local administration or any other organization with the responsibility of providing services that ensure safety and security of citizens who are under risk or affected by an emergency event.

A wide range of varying number of PSC-enabled interactions is possible in emergency scenarios. The ETSI Special Committee on Emergency Telecommunications (EMTEL) has produced the following classification[13]:

- *Communication between authorities*[14], for instance, between mobile field units (e.g., ambulances, fire engines, police patrol units) and emergency command and control centres;
- *Communication from citizens to authorities*, typically initiated by citizens as emergency calls to PSAPs (e.g. by dialling emergency number 1-1-2 in Europe or 1-1-9 in South Korea);
- *Communication from authorities to citizens*, usually implemented as public or commercial alerting services (broadcast SMS of an impending hazard event);
- *Communication between citizens* during emergencies, enabling victims and relatives or friends to stay in contact (e.g. through social media channels) during or after an emergency.

Inability to communicate and share information effectively or reliably in any of the aforementioned categories may undermine emergency response operations; result in unnecessary panic and exert further pressure on limited authority resources. Therefore, the best (and guaranteed) service quality, instant availability and reliability are paramount considerations for communications infrastructure and services intended for PSC purposes.

The leveraging rich multimedia solutions (e.g. immersive video services) and unconstrained operational data sharing in emergency interactions, enhances information sharing for improved situational

[12] Public Safety Communication Europe, https://www.psc-europe.eu/

[13] ETSI SC, EMTEL Emergency communications, http://www.emtel.etsi.org/

[14] This also referred to as Public Protection and Disaster Relief (PPDR) communications

awareness, and boosts operational efficiency of emergency responders. However, these services and applications place increased demands in terms of stringent quality-of-service guarantees and resource requirements on the underlying network infrastructure, which in most cases are authority-owned (closed) PMR networks or PLMNs provided by commercial MNOs. As a result, the envisioned performance and architectural enhancements of 5G have drawn significant attention[15] from public safety community that has traditionally had to contend with performance limitations and inflexibilities in legacy mobile networks. The PriMO-5G project contributes to theme by researching the potential of 5G (and beyond 5G) technologies to selected firefighting scenarios.

All regions around the globe are working with evolving the public safety:

- **US:** In the US they found out shortcomings already sept 11 2001. Since then First Responder Network Authority and AT&T has evolved FirstNet with more than 10,000 different radio networks across the country. A core benefit of FirstNet is the nationwide licensing of dedicated Band 14 spectrum. Having a dedicated band for public safety communications means that all needed voice, data, video and text traffic are channelized over the dedicated band. FirstNet provides the capability for all LMR traffic to be linked to the AT&T LTE cellular network. Hence, agencies can continue to use the LMR systems they have invested in, while adding to the situational awareness of incoming units that traditionally do not have access.[16]
- **India:** Nokia and BSNL plan to deploy an LTE public safety system which will explore solutions to help first responders to more swiftly locate people and assist affected communities.[17] The collaboration will assist in advancing public safety standards in the country and support the Indian government's Smart Cities Mission. By establishing an LTE network, first responders can securely transmit large images and videos in real-time to other workers and command centres, providing vital insight into a situation to aid public safety and rescue efforts.
- **Europe:** PSCE, the Public Safety Communications Europe Forum, was established as a result of a European Commission funded project in 2008. Since then, PSCE has evolved into an independent forum, where representatives of public safety user organisations, industry and research institutes can meet to discuss and exchange ideas and best practices, develop roadmaps and improve the future of public safety communication. On 12 and 13 February 2019, the 5G Vertical User Workshop, an initiative of 3GPP Market Representative Partners 5GAA, 5G-IA, 5G-ACIA and PSCE, was organised as a collaborative event for strategic dialogue between industries and 3GPP and brought together a host of experts from 5G standardization and a number vertical industries hoping to harness 5G including Automotive, Public Safety, Industry Automation, Utilities, Broadcasting, Satellites and Railways; as well as policy makers at the EU and Member State level.[18]

[15] D. Lund, D. Corujo and R. Aguiar "When will 5G be ready for use by PPDR?" PSCE White Paper, December 2018 https://www.psc-europe.eu/news-events/news/383-new-psce-white-paper-on-5g-ppdr-needs.html

[16] AT&T White paper: "How Firstnet can ease the burden", Ryan Fields-Spac, 2018.

[17] Press release: Nokia: Nokia and BSNL to jointly explore public safety initiatives in India leveraging Nokia ViTrust critical communications portfolio, 23 October 2018.

[18] PSCE co-organises 5G-Verticals Workshop in Brussel, 18/02/02019, (PCSE, Public Safety Communications Europe)

3.2 Firefighting

Fires are a growing issue for the modern society. Climate change is progressing and there is a likelihood that fires will increase[19] [20]. Fires can be categorised in different types, e.g. forest fires or urban fires[21].

Many countries are nowadays facing new challenges for firefighting as uncontrolled wildfires or forest fires are increasing in numbers, size and complexity. To add in many cases, there may be parallel fires ongoing. They may be spread across a whole country and this of course puts heavy requirements on the society.

Firefighting is therefore coming up as one of the key areas for governance protection of the society and has also triggered international co-operations. In Europe there is a common investment into firefighting aircrafts and during the wildfires in Sweden 2018 there were several nations co-operating on the firefighting as well as with support of the European common resources of firefighting aircrafts. This of course increases the need for governance within countries as well between countries.

Fires are very dynamic and hard to predict. Environmental conditions such as wind, heat and the existence material of fire can easily change direction and size of a fire. What started as a forest fire can very soon transfer into a complex fire situation where critical properties of the society can be threatened, e.g. dams as well as areas with buildings, such as single houses, villages, cities or industrial areas.

Even more important for the society is to lower the risk for the emergence of fires which means that the society needs to do assessments of fire risks, communicate regulations and even do preventive supervision. Communication systems can play an important role for preventive measures.

Fires and firefighting have a set of phases as illustrated in Figure 3-1. There are different needs on the firefighting communication system connected to each phase.

Figure 3-1: Phases of fire

3.3 Governance of fires

Firefighting is a core area for countries. It is in most cases part of the total defence planning for war times but nowadays national emergency situations can also occur as the result of the environmental challenges that follows the climate change.

The dynamicity of fire put heavy requirements on the public safety organization adapting to the emergency case. It involves 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 military, to having the right supporting frameworks in place at the right time with the right performance.

The society therefore organizes firefighting on different levels, see the table below:

[19] United Nations, Climate change annual report 2017, https://unfccc.int/resource/annualreport/

[20] S. W. Running, Is Global Warming Causing More, Larger Wildfires?, Science 18 Aug 2006, vol 31, issue 5789, pp. 927-928.

[21] United Nations, Office for Disaster Risk Reduction (UNISDR), https://www.unisdr.org/

Table 3-1: Organization of firefighting on different levels

Planning level	Level of society	Tasks
Strategic	National	• Preventive supervision system for fires • National prioritization fire control and fire resources • International agreements of public safety • Inter-country investments in firefighting, e.g. firefighting aircrafts • International synchronization of fire-fighting resources • National public safety bodies • National management centres, including staff functions for emergency cases • Coordination with military; e.g. for precision bombing of fires • Public safety infrastructure plans
Tactical	Regional	• Preventive regional supervision systems • Regional synchronization of public safety functions • Strategic/tactical alignments • Regional public safety bodies • Regional evacuation plans • Regional management centres, including staff functions for emergency cases • Planning and operations of base camps for national and international public safety functions, e.g. firefighting resources • Public safety infrastructure plans
Operational	Community	• Firefighting functions on community level • Public safety synchronizations on community level • Sets up evacuation centres • Sets up base camps • Tactical/operational alignments • Public safety infrastructure plans

3.4 Components of public safety communication systems for fire situations

There are many requirements on a public safety communication system for firefighting situations:

- The Public safety communications system must be able to integrate with the strategic, tactical and operational levels for the firefighting effort.
- The public safety communications system must be easy to set into operations and be able to be deployed fast to dynamic situations
- The public safety communication system must be able to fill gaps of existing infrastructure, strengthen the communication and be able to easily integrate to the existing environment
- The public safety communication system must be able to interact with other public communication systems, e.g. air traffic control system.

Finally, a preventive system for fires can be set into operation that can detect fires or risk areas on national, regional and community levels to reduce time for actions.

Below follows a figure of components of a public safety communication system for fire situations, see Figure 3-2:

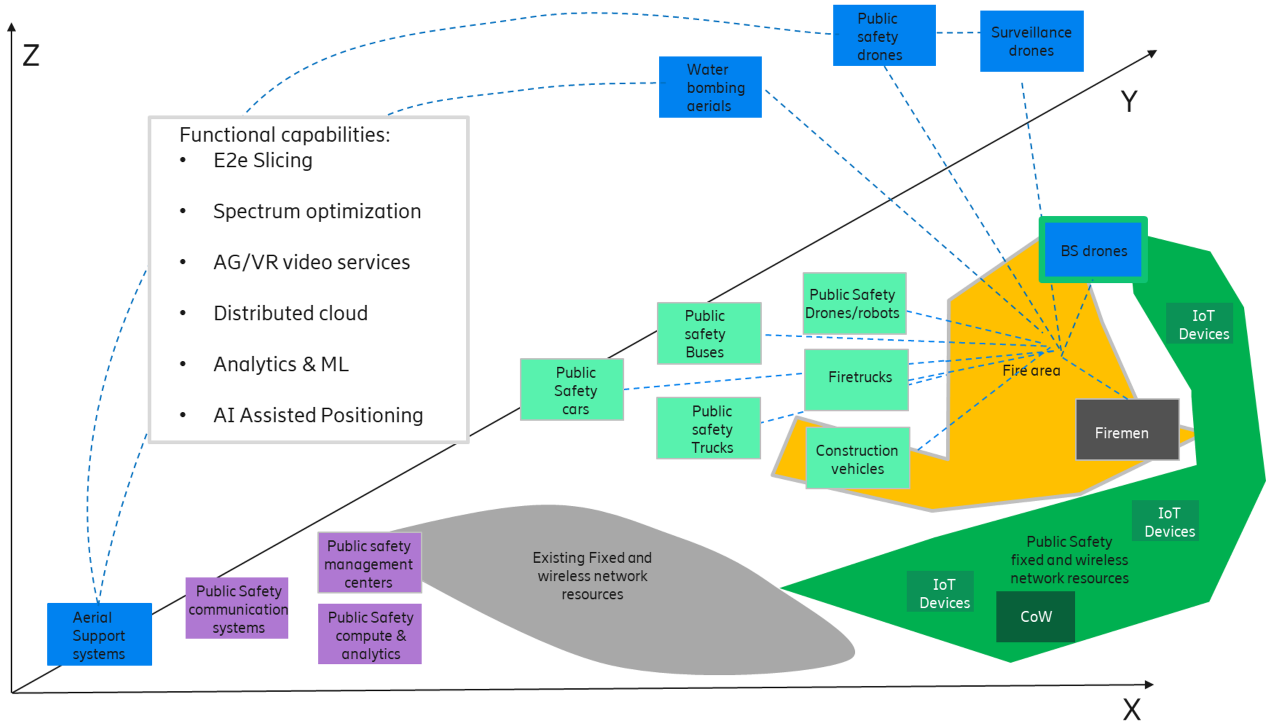

Figure 3-2: Components of a public safety communication system

There are many sub use cases for the public safety communication system. Therefore, there are many requirements on potential components of a public safety communication system. The inclusion of aerials also means that the components cover a 3-dimensional space.

3.4.1 Functional Capabilities

- E2E Slicing can be done for various purposes: drone control, collision avoidance, services (e.g. video), public safety functions (e.g. police, medical), public safety management (strategic, tactical, operational)
- Available spectrum options for the existing public systems and the public safety communication system (location-based spectrum, integration of spectrum usage between systems)
- AR/VR systems: for public safety functions: e.g. firemen, police, and medical system integration towards public safety communication centres
- Distributed cloud: enable local processing and analytics
- Analytics and ML: gather data from different sources, perform analytics and present results to various stakeholders
- AI assisted positioning: of everything that could be positioned, Tubes, vehicles, people

3.4.2 Components of the public safety communication systems

The components below are described with reference to Figure 3-2, from left to right.

- **Aerial support systems**; the public safety communication system must be able to integrate towards existing public systems for aerials, such as air traffic control, UAS management and other public aerial systems for drones and aircrafts or towards other ground support systems. One of the areas where the aerial support systems and the public safety communication system can interact is how to control aerials and avoid collisions.
- **Public safety communication systems;** public safety communication systems are supporting the needs for both external communication towards the public as well as secure internal communication towards public safety functions. It can be announcements for the public, evacuation information or just facts and Q&A that can be derived from created webpages that provides information about the public safety operations.
- **Operation management centres**; public safety management centres have the operational responsibility for the public safety effort. Integration of all data resources that is valid for decision making are needed.
- **Public safety compute and analytics**; public safety computing and analytics. It is very likely that computing, analytics and machine learning capabilities are integrated closely with the public safety centres. But also distributed analytics can be provided to limit data or provide local data.
- **Integration support to fixed and wireless network resources;** existing fixed and wireless network resources are often inadequate to cater for the firefighting communication needs. Several operators may have access points. Regulations may be needed to support easy integration of public safety communications systems. Operators are most likely to be more than willing to support a firefighting situation as a fire can both threaten their customer base as well as destroy infrastructure. Public safety fixed and wireless network resources must be easy to integrate into existing fixed and wireless network resources. For areas with limited communication capabilities fast core network rollout must be provided, whether it is fibre on top of the ground, microwave link or other alternatives or combinations of the above. As fire can evolve directionally fast it must be considered whether it is safe to provide the core network. At a certain length from the fire the public safety network resources will most likely be focused on wireless solutions.
- **Support of RAN with mobile and aerial BSs**; it must be able to complement the public safety communication system with mobile and aerial BS to be able to handle the dynamic conditions of fire. These drones can also be used to provide cell detection services. The drones should be able to support different drone architectures and be able to be operated as a fleet or a swarm.

- **IoT connectivity**; IoT devices may be deployed to cater for sensor systems, e.g. tracking of fire tube deployment or nearest water resource.
- **Data enabled fireman;** firemen can be data enabled and provided with video capabilities. A data enabled fireman ´can send and receive video as well as map information, directives and facts that can be of advantage in the firefighting effort. Firemen could also provide local control of public safety drones/robots.
- **Public drones and robots;** public drones and robots can provide services for several public safety functions: e.g. to provide input data for police operations. The public safety drone and robots can be controlled locally or centrally. Different degrees of autonomous control can be applied and they can be either manned or unmanned.
- **Fire trucks:** fire trucks can be provided with local edge capabilities and act as some sort of command post to maximise local firefighting efforts.
- **Water bombing aerials;** water bombing aerials can be of different types; aircrafts, helicopters, water bombing drones or military aircrafts (precision bombing of fires). The water bombing aerials can be manned/unmanned and/or autonomous or manual. The water bombing aerials could be operated as a fleet/swarm or independent.
- **Public safety cars, buses, trucks and construction communication;** public safety cars, buses, trucks and construction vehicles have basic communication needs. However, they can all be enhanced with tracking, positioning and data capabilities. Even video could be considered with VR/AR capabilities. The vehicles can support different public safety functions and can have local data information or communication.
- **Legacy and public surveillance systems;** existing surveillance systems can be complemented with drone surveillance systems provided from the public safety communication system. The surveillance systems must be enabled to provide the management centres with data for the public safety effort. Surveillance systems can also be used in preventive functions to detect fires.

4 PriMO-5G scenarios and use cases

This section introduces scenarios capturing and stressing the main challenges addressed by the PriMO-5G project. As discussed in Section 3, this project selected firefighting as a focus area where immersive video services utilizing UAVs can make the job safer and more efficient. In this section, we will consider the drones to be the main type of the UAVs.

Based on the general description about the firefighting and the corresponding public safety communication systems, we present two scenarios in this section; one is about forest firefighting in rural areas and the other is concerned with preparatory and supporting actions for firefighting in urban areas. Then, use cases associated with the scenarios are presented. Each scenario starts with a narrative of a scene related to firefighting. Then, it defines actors involved, and describes interaction between the actors. The scenario is detailed by use cases which describe the technical aspects. The use cases particularly consider the communication and computing perspectives.

4.1 Scenario A. Forest firefighting with robots and UAVs

Assume that a fire breaks out in a rural forest. Fire trucks have difficulties in reaching the fire scene due to the inadequate road condition. Firefighting equipment is too heavy for human firefighters to carry. Fallen trees are dangerous obstacles in the scene. Fire can expand quickly at any time, which may risk the safety of firefighters.

We envisage that robots and UAVs can play significant roles in such circumstances in a near future. Robots have the great potential to make the fire scenes safer to the emergency response personnel and the firefighting more efficient. The possible use of robot technology ranges wide; for example, fire extinction, localization and rescue of persons, measuring of toxic or hazardous substances, transportation of equipment, and manipulation and clearing of obstacles and hazardous objects.[22] Robots of various shapes and functionalities have been developed and are under research for the firefighting.[23] While the robots act as replacements of human firefighters for hazardous and physically demanding tasks, UAVs mainly perform a supporting role. The main duties of the UAVs would be to gather visual and location information of the fire scene and to facilitate communications between the actors.

We consider a scenario that a team of firefighters and robots performs a coordinated operation in a forest fire scene with the aid of a fleet of UAVs. The main requirement of the scenario is that ***all team members, both robots and human personnel, know exactly what to do*** for the safety and efficiency of the firefighting operations. This needs timely and relevant operational decisions and proper communications.

The actors in this scenario are defined below.

- Human firefighters
- Incident commander at the local fire scene
- Robots for firefighting and supporting roles
- UAVs
- Mobile network operator
- Spectrum regulator

Notice that the water-bombing aerial can be categorized into robots in this scenario because the water-

[22] F. E. Schneider and D. Wildermuth, "Using robots for firefighters and first responders: Scenario specification and exemplary system description," in Proc. IEEE 18th International Carpathian Control Conference (ICCC), 2017.

[23] P. Liu, H. Yu, S. Cang, and L. Vladareanu, "Robot-assisted smart firefighting and interdisciplinary perspectives," in Proc. IEEE International Conference on Automation and Computing (ICAC), 2016.

bombers (aircrafts, helicopters, drones) directly participate in the fire extinguishing actions.

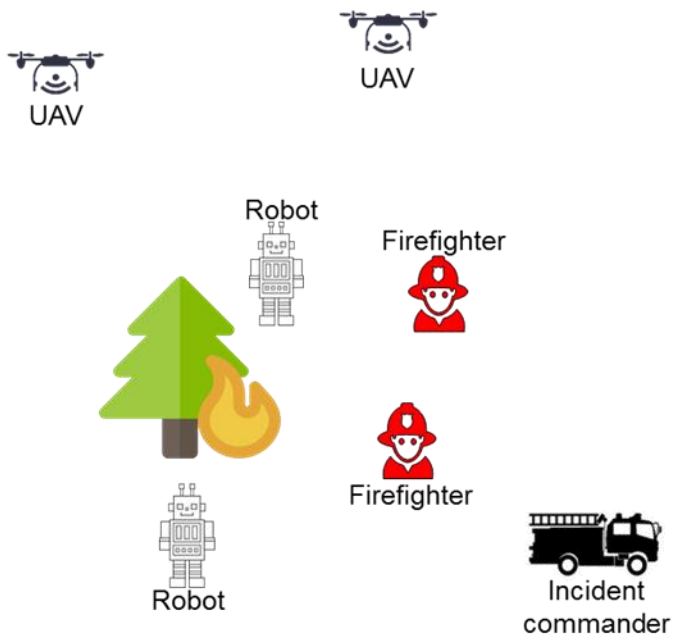

Figure 4-1: Actors of scenario A who are directly related to firefighting operations

Some actors are directly related to the firefighting operations. See Figure 4-1 for a graphical description of them. The roles and requirements of these actors are described below.

- **Robots** help and may even replace human firefighters in fire extinction. They also relieve the burden of firefighters by carrying heavy equipment and clearing obstacles. Some robots can have sensory capability to localize people to be rescued and to detect toxic or hazardous substances. The robots have two main requirements: information acquisition and communication. One of the main challenges of robot operations is the lack of information at the robot side. The visibility in the fire scene is normally limited due to obstacles, smoke, gasses, or dust. Location information is also difficult to obtain because the buildings or forest trees may obstruct the reception of GPS signal. Tumbledown architecture, fallen trees, and the debris alter the scene from the previously known map even if the robots have the detailed map information in advance. Therefore, the robots need to be provided with the relevant information about the fire scene. Together with the information, the robots need to receive timely commands from the incident commander or personnel nearby. The visual and sensory information collected by the robots also needs to be delivered to the nearby robots/firefighters and the incident commander.

- **Firefighters** basically perform the same tasks they do today. The difference in this scenario is that the firefighters have robots as new teammates. So, they can and should utilize robots as much as possible for their own safety and more efficient operations. For this, the firefighters have similar requirements as robots. They need to have accurate information on the fire scene, and need to communicate with other humans, robots, and the incident commander. Additional requirement for the human personnel is the ease of use. The firefighters should be able to obtain information, communicate with others, and control nearby robots without being distracted. When the visibility of the firefighters is impaired by smoke or blockage, augmented reality (AR) technology can assist the firefighters to “see-through” the obstacles[24]. This would help the firefighters prepare for the upcoming situations.

- **Incident commander** is human personnel who oversees the fire scene and makes decision on the placement and role of each robot and human team member. Therefore, the incident commander requires global information about the fire scene so that he or she can place the robots and personnel at the right spot and make the strategic decisions about the firefighting operations. Virtual or augmented reality would be helpful for figuring out the current state of the fire scene. Reliable communications with the firefighters and robots must be ensured. The incident commander may need to communicate with a control centre which is far from the scene (normally located in a city) to make strategic planning if the size of the forest fire is large. It requires a long-distance connection, either direct or through existing infrastructure, between the incident commander and the control centre.

- **UAVs** act as a facilitator of other actors. As described above, robots and human firefighters have difficulty in obtaining visual and location information of the fire scene. The major role of UAVs is to provide such information for them. Incident commander is behind the fire scene, and thus is heavily reliant on the overall information about the scene that the UAVs provide. A fleet of UAVs can create virtual and augmented reality for the incident commander, e.g. wider view screen that can turn around from different angles. Further, the UAVs serve as relay for the communications between the ones at the scene (robots and human firefighters) and the incident commander behind the scene. Note that a fire scene is typically full of obstacles, and thus has poor coverage of wireless communications. Aerial relay is an effective tool ensuring the reliable communications for firefighting.

Besides, the following actors also play important roles in setting up environments for the envisaged firefighting.

- **Mobile network operator** is expected to take an active role in public safety communications in general, and thus will be an important part of communications infrastructure for this scenario as well. The communications between the aforementioned actors can be through the existing infrastructure that the MNO has. Furthermore, the MNO can provide computing resources to aid the smart operations of the actors. However, in a rural forest, coverage of MNO is not always guaranteed especially for high data rate provisioning. It is possible that the fire area is out of MNO’s reach except for traditional voice and low data rate services. For this case, the MNO is almost excluded from the scenario and its role is reduced to providing a backhaul connection between the incident commander and the control centre.

- **Spectrum regulator** is responsible for the radio spectrum that the aforementioned actors use for the communications. Clear guideline on the frequency band and authorization scheme should be provided.

4.1.1 Use case A1. Placement of communication and computing for forest firefighting

4.1.1.1 Overall description

Scenario A requires a system which supports communications between the actors as well as computing such as VR video processing and swarm management. An important issue in the system design is where the communication and computing functions should be located. Thus, in this use case, the actors of Scenario A are seen as communication and computation devices with different functionalities and capabilities. Figure 4-2 illustrates the overall use case description.

A mapping of each actor to the communication and computing is as follows:

- **Firefighters** are assumed to be simple UEs. Since the firefighters a wear heavy body armour

[24] See, for example, https://www.qwake.tech/

and carry equipment, their communication devices must be light-weight. Therefore, firefighter performs no other functionality than UE in this use case.

- **Robots** can be of mixed types. Some robots are simpler and are regarded as UEs like human firefighters, and other type of robots are equipped with more powerful devices acting as moving gNBs to connect other robots and firefighters nearby.
- **UAVs**, similar to robots, can also be of different types. One type of UAV only needs to communicate with other UAVs for collective (swarm) operations and visual crowd-sensing. Other type of UAVs performs more functionality. It is an aerial gNB which connects firefighters and robots to the incident commander. It can also be an anchor point of other UAVs. If the existing cellular infrastructure is available at or near the fire scene, some UAVs may connect through MNO's fixed gNB.
- **Incident commander** is assumed to locate at a fire engine which is capable of gNB and MEC functions. MEC is essential for the processing of real-time immersive video from the information that UAVs sent. If the fire break-out is in a large scale, the incident commander will need connectivity to the control centre. Thus, the fire truck should also have wireless backhaul to the closest available infrastructure.

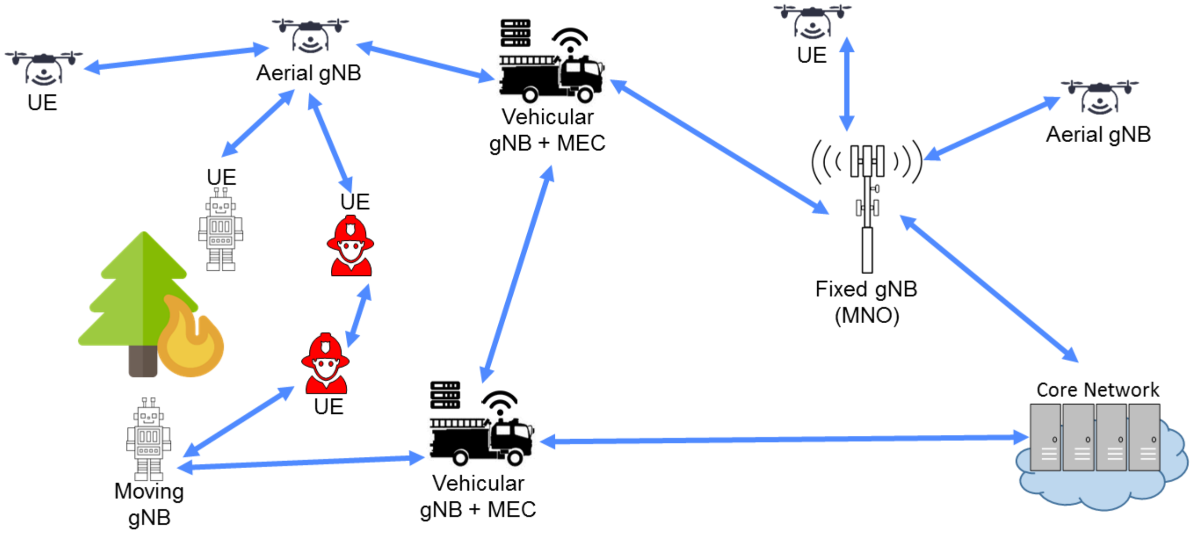

Figure 4-2: Illustration of drone-assisted smart robot firefighting

4.1.1.2 Identified requirements

The use case A1 can be broken down into three layers of requirements: operational, functional, and technical requirements. Detailed description of each layer is as follows. As for the technical requirements, we focus on the perspectives of communications in this section.

Operational requirements

- The firefighting robot is aware of its location and its surroundings.
- The firefighting robot receives timely commands from the incident commander.
- The incident commander has real-time VR video of the fire scene.
- The firefighters have real-time AR video for visibility enhancement.

- Location of all nodes is available in the network.

Functional requirements

- Visual crowd-sensing of the videos taken from multiple UAVs.
- Real-time VR and AR video processing from the information obtained by the drones and the robot.

Technical requirements

- Communication between the drones for fleet control and visual crowd-sensing.
- Communication between the drone and the firefighting robot for the awareness of fire scene and command messages (forward link), and for local information obtained from the robot (reverse link).
- Communication between the drone and the mobile command centre for the video taken from the drones and the relaying of local information (reverse link), and the relaying of command messages for the robot (forward link).
- Wireless backhaul between the mobile command centre and communication infrastructure.
- Dynamic handover for low-latency application.
- Radio-based measurement for positioning.

4.1.1.3 Identified research challenges

From the functional and technical requirements, various research challenges can be identified. These include, but are not limited to:

Radio spectrum to be used

- 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 MNO for the case of emergency can be an option. Feasibility of using license-exempt spectrum can also be studied.

Trade-off between communication and computing

- Consider that a crowd-sensed visual data from a fleet of UAVs is provided for the incident commander as a real-time VR video. This service needs both high data rate communications and heavy video processing. However, different technical solutions have different combinations of requirements for the communication and computing tuple. For example, one can design a solution, which relies on fast communication links to deliver several high-resolution videos to MEC so that MEC only needs to stitch the videos with minimal computational load. Alternatively, MEC can run a computationally heavy algorithm to minimize the load on the communications side. Striking a right balance between communication and computing is a profound challenge in this use case.

Fast-changing communication link quality and availability

- The communication between the actors may be affected by the likelihood of LOS. Due to the high data rate required for the delivery of high-quality immersive video, mmWave frequency bands with large bandwidth can be considered, which prefers LOS propagation environments much more to the NLOS environments. As illustrated in Figure 4-3, the requirements for LOS in mmWave may necessitate additional aerial relays for some of the communication links.

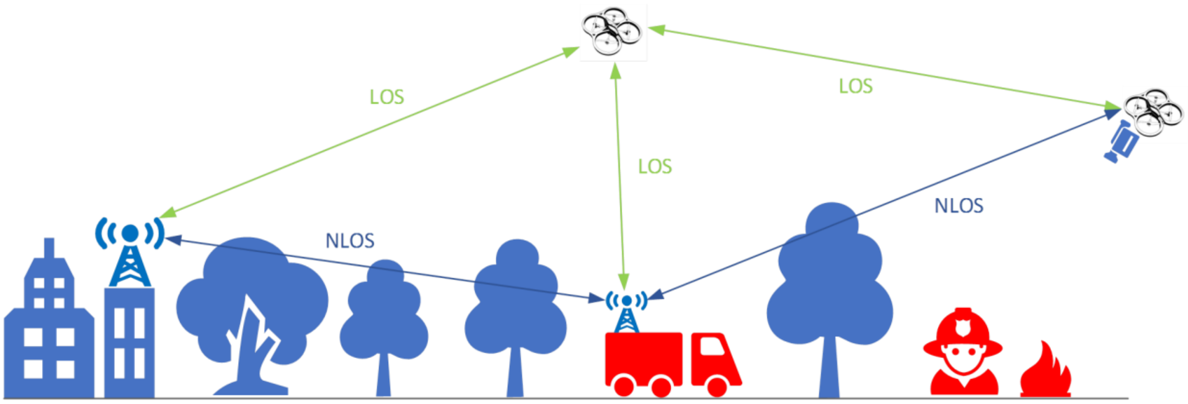

Figure 4-3: LOS requirements for the communication links

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 GNSS system. Different implementation can be considered including centralized (in the network) and distributed (local at each node).

Dynamic service migration

- 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.

4.1.2 Use case A2. Network slice management for forest firefighting

4.1.2.1 Overall description

In firefighting scenario the same infrastructure is used for all the communications systems and it applies best effort traffic priorities. However, in emergency situations there are various types of communications with different requirements, and they have to be allocated to different network slices to ensure dedicated resources for each communication need. For example, command messages from the incident commander to drones and robots require Ultra Reliable Low Latency Communications (URLLC). On the other hand, video transfer requires higher bandwidth and low latency, but can allow a certain delay compared to the command messages. Therefore, in order to satisfy different requirements for the communications during firefighting event, network slicing plays a key role.

This use case describes how network slicing can utilize the available network resources and create slices for each type of communications with their specific requirements in terms of latency, bandwidth and packet loss. Figure 4-4 illustrates the different network slices required during firefighting operation.

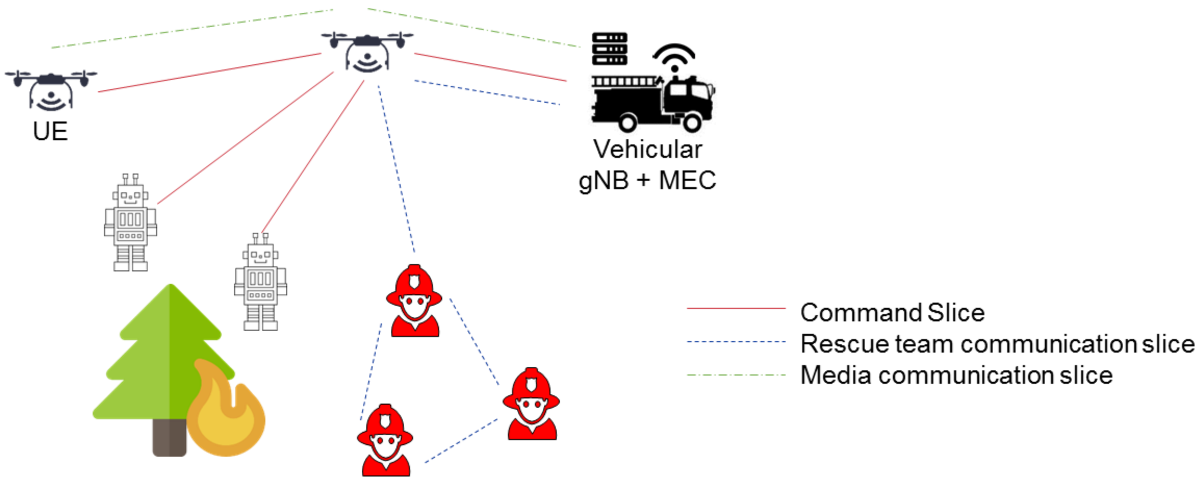

Figure 4-4: Illustration of network slicing for drone-assisted firefighting

A mapping of each actor to the communication and computing is as follows:

- **Firefighters** are equipped with UEs and will be allocated to high reliability network slice.
- **Robots** will be simple UEs and will be allocated specific network slices with and without low latency requirements depending on whether they are for management or data transmission. The robots that are equipped with moving gNBs will be managed remotely to allocate network and radio slices required for other devices with low latency requirements such as UAVs.
- **UAVs**, similar to robots, can be simple UEs which are users of network slices or UAVs that carry aerial gNB which then should be managed from URLLC controller. If the existing cellular infrastructure is available, the MNO should provide access to network slice manager to configure the URLLC requirements to connect the UAV to the rest of system.
- **Incident commander** is assumed to locate at a fire engine which is capable of gNB, MEC and URLLC network slice management functions. If the fire break-out is in a large scale, the incident commander will need connectivity to the control centre. Thus, the fire truck should also have wireless backhaul to the closest available infrastructure.

In a firefighting scenario there are communications that require ultra-reliability and low latency for managing the drones and robots. This set of communications should have own network resources or slice allocated to enforce the tight requirements of latency. Voice communications between the firefighting team requires lower bandwidth and they are packet loss tolerant. Therefore, enabling different type of communications with own constrains require network slicing to ensure their specific needs in terms of latency, packet loss and bandwidth.

4.1.2.2 Identified requirements

The use case can be broken down into three layers of requirements: operational, functional, and technical requirements. Detailed description of each layer is as follows.

Operational requirements

- The network infrastructure supports network slicing and RAN, Transport sharing.
- The network infrastructure includes enough resources to fulfil the total required bandwidth.

Functional requirements

- The network switches between the gNBs and the mobile core support SDN to activate network slices.

Technical requirements

- The drones or other UEs can maintain double connectivity with same or different eNBs to guarantee reliable connection.
- Communication between the drones and command centre for drone management.
- Communication between the UE equipment of firefighting team members.
- Communication between the drone and the mobile command centre for the video taken from the drones.
- Wireless backhaul between the mobile command centre and communication infrastructure.

4.1.2.3 Identified research challenges

From the functional and technical requirements, various research challenges can be identified. These include, but are not limited to:

Limited network resources

- The UAV may need to act as gNB and additional resources are required to enforce the URLLC traffic priorities in the gNB.

Wireless links with low reliability

- The link between the UAV when acting as gNB and the control centre requires high reliability to ensure the management of resources from the control centre. The UAV might require multiple links e.g. disjoint paths connected simultaneously to ensure high reliability.

4.2 Scenario B. Smart firefighting with UAVs in urban area

Rapid industrialization caused unplanned and haphazard urbanization. In the same manner, the roads were constructed carelessly and loosely to meet the needs of rapidly growing urban population. So the streets tend to be very complicated with the lack of standardization. The traffic congestion of a big city limits the mobility of fire engines, and the sudden appearance of a fire engine is unpredictable to drivers. This may cause a belated action of drivers which prevents the fire engines from reaching the scene on time. Moreover, in industrialized cities, flammable materials are used anywhere which can cause secondary accidents. Those situations are highly risky to densely populated areas. Fortunately, UAVs are capable of approaching the critical areas much faster than the fire engines and firefighters. Thus, UAVs are predicted to be increasingly helpful for firefighting in urban area.

While the firefighting equipment and human firefighters are on their way, fleets of UAVs can reach the fire scene first as they can travel straight through the air space. The air fleets can take preparatory measures, such as evacuation of people, search for persons to be rescued, and surveillance of dangerous materials to prevent secondary accidents in the near fire area. The drones can actively lead the evacuation procedure by telling (e.g., the evacuation instructions and warnings from the commander), showing (e.g. the evacuation path to the victims and the spectators), and providing (e.g., masks and other safety equipment). In addition, the aerial view from high altitudes can also assist the fire engines to take faster actions and firefighters by navigating the optimal route to the area.

Similar to the Scenario A in Section 4.1, we consider that a team of firefighters and UAVs performs a coordinated operation. The primary requirement of our scenarios is that UAVs are doing the preparatory measures and providing the information for firefighters so that they can reach the scene faster and know what to do right after the arrival for the safety and efficiency of the firefighting operations. Some actors of this scenario are directly involved in the firefighting: the UAVs, the human firefighters, and the incident command system. Each of the actors should satisfy specific requirements.

- **UAVs** play an important role in preparatory actions for the smart firefighting. It includes searching for survivors, and observation of the fire scene. The UAVs should be able to collect information on a large area, not only the fire scene but also the surroundings, and deliver that sensory information to the incident commander. The UAVs also need to react promptly to the command messages to search for survivors, detect flammable chemicals and/or toxic gases, and watch over the fire scene.

- **Firefighters** are the main agents of rescue activities. It is critical that the firefighters obtain the appropriate information such as safest route to the fire scene, status of the fire spreading, medical conditions of victims, and characteristics of the fire to effectively deal with each unique fire situation. They should be able to communicate with each other, UAVs, and the incident commander.

- **Incident commander** is capable of gathering large-scale real time overview and capturing various emergency situations. With this situational awareness, incident commander determines the best way for a rescue, and provides it to the drones and the firefighters, so that they can carry out their roles more effectively.

Mobile network operator and spectrum regulator are other important actors.

- **Mobile network operator** is assumed to have well-established infrastructure in urban areas, which is very different from the rural cases. Thus, MNO can actively be involved in the communications between the firefighting actors. However, the fire scene may become a temporary coverage hole due to equipment failure, and the spots near the fire scene may suffer from the surge of traffic demand. Therefore, resource allocation which quickly adapts to the current network status and traffic demand of the firefighting team is a challenging issue for the MNO.

- **Spectrum regulator** has the same role as in Scenario A. It is responsible for the radio spectrum that the actors use for the communications. Clear guideline on the frequency band and authorization scheme should be provided.

Finally, cars and people are the actors who can affect and be affected by the firefighting.

- **Cars** on the road act as the obstacles, which hinder the movement of fire trucks. The cars should be informed of the appropriate actions to yield to the fire trucks. If some cars do not react properly, that information must be taken into consideration for the optimal route planning and firefighting operations.

- **People** need to be evacuated quickly and safely from the fire scene. It is essential to provide timely information, and preferably detailed directions of evacuation, for the people at or near the fire scene.

4.2.1 Use case B1. UAV-assisted preparatory measures for smart urban firefighting

4.2.1.1 Overall description

UAVs offer a great opportunity to provide a real time overview and detect potential catastrophic accidents. Fleets of UAVs can provide insightful awareness of a fire scene from their sensory information to firefighters and incident commander. Fast and reliable wireless communications are essential for these kinds of operations. Unfortunately, the current fire emergency rescue system does not exploit the advantage of radio technology effectively. To explain, the current system utilizes the information acquired from the phone call with the primary informer of the situation (e.g., situation awareness, GPS information), but it does not exploit the highly reliable and low latency communication, mobility, connectivity, and high network capacity that advancements in radio technology promises. To add, by utilizing the existing and upcoming wireless infrastructure, we expect to deliver efficient utilization of computing resources on site, in the MEC, and the fire station for services that aid the firefighting procedure. The following key advancements allow us to support the agents in different ways:

- **Connectivity**: All drones are connected to the fire engine and the fire station. This connection enables the firefighters to control each drone fleet member directly and gather information from them when necessary. Also, the drones could actively exchange information while executing individual evacuation missions, which is critical for the reliability of the missions.
- **Low latency**: Real-time streaming of video from the fire site and low latency communication towards the site enable firefighters on fire engines to engage in the situation and get full awareness of the situation, despite their distance from the actual site. Peer to peer communications between drones added on top of 5G network help utilize the computing resources more collectively and cooperatively.
- **Reliability and Capacity**: Increased capacity allows multiple feeds with different emphasis to be streamed simultaneously. Massive amount of information collected by the drones are valuable resources that could later be used for machine learning database. Ground control station, GCS, trains and updates machine learning model to perform accurate image detection, and GCS executes overall orders according to the received information.

Figure 4-5 illustrates a firefighting system, which is assisted by the preparatory measures of UAVs. This use case assumes a fire in densely crowded urban area.

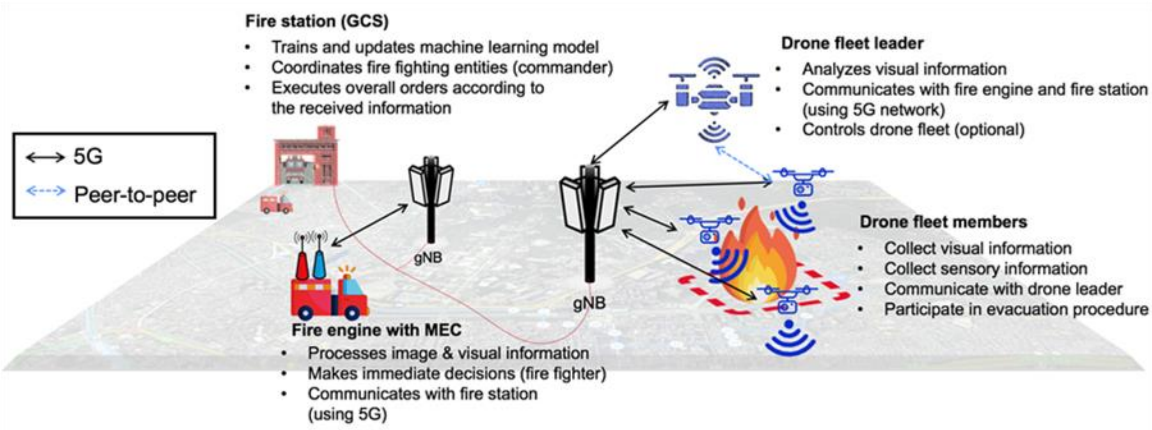

Figure 4-5: Illustration of UAVs assisting smart firefighting in urban areas

The UAV fleets provide an overall awareness of the fire scene by using their sensory equipment such as camera and thermometer. Information coming from drones contributes to determining the best approach for a rescue and firefighting operation. The leader drone can guide drones and MEC to obtain and process appropriate information. A MEC will be located in the fire engine that can make the optimal fire extinguishing and rescue plan at the scene.

Table 4-1: Operational hierarchy of firefighting entities

Entity	Processing requirement	Delay requirement
Fire station (control station)	Heavy	Long
Fire engine (MEC)	Moderate	Moderate
Fleet leader (high-end drone)	Light	Short
Fleet members (drones)	Real-time	Real-time

Effective communication between the entities is crucial because they act collectively to achieve a certain goal (e.g., evacuation, fire extinguishing). Also, unforeseen events around the fire site resulting in a sudden change to an entity calls for an immediate update, which requires delay critical communication. Different entities have different resources and a corresponding processing-delay trade-off as shown in Table 4-1. Thus, tasks should be sliced, customized, and allocated to each entity or group, according to the individual capabilities, to meet the overall requirements.

4.2.1.2 Identified requirements

Detailed descriptions of the requirements are categorized into: operational, functional and technical requirements.

Operational requirements

- The drones interact with the people near and inside the dangerous site by telling, showing, and providing them necessary information or objects.
- The drone has the ability to detect sensory information around it.
- The incident commander should have the capability to receive and process real-time streamed video of the fire scene.

Functional requirements

- Changes in mission status of each agent due to unforeseen events are updated to its leader immediately to reallocate the tasks.
- The task of visual information processing is allocated to either the UAVs or the MEC depending on the computing power of each device and the reliability of sensed information provided by the UAVs.
- MEC can perform intensive image processing to provide an immersive experience to the firefighters on board.

Technical requirements

- The optimization of computing resources with respect to the computing/latency hierarchy of the different agents.
- Communication between the drones for fleet control and visual crowd-sensing
- Communication among drones, MEC, and the firefighters for sharing important information from the fire scene and fire station.
- Reliable networks between the firefighting entities for detecting information on a fire scene and for controlling the drone fleet

4.2.1.3 Identified research challenges

From the functional and technical requirements, various research challenges can be identified. These include, but are not limited to:

Trade-off between communication latency and computing power

- In general, higher computing power involves higher levels of power consumption and highly integrated and massive circuit architectures. It means that computing power and mobility of entities are inversely proportional. The objects with high mobility (e.g., drone fleet members) can be located closer to the scene of the disaster, thus the computing power of the object can be reduced. This means that computations that require a high level of computing power cannot be performed near a disaster site. For this point, wireless communication can be used as a solution. However, transmitting high-resolution images to the location with high computing power - for accurate visual information analysis - inevitably introduces communication latency problems. In consequence, the trade-off between communication latency and computing power is one of the major research topics in this urban scenario.

Simultaneous video transmission of live streaming and high-quality and reliable 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 can be 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.

4.2.2 Use Case B2. Differentiated UAV fleet management for smart urban firefighting

4.2.2.1 Overall description

At the incident site of fire, a variety of information is necessary for the command centre to provide appropriate guidelines to the firefighters. Each type of information has different set of requirements. VR video of the fire scene should be delivered in real-time with high data rate requirement. On the contrary, information about the surroundings (e.g., traffic situation, potential risk of secondary accidents, etc.) can bear some delay but needs high reliability.

This use case is concerned with classifying the drone fleets for collecting and delivering different types of information. For example, drone fleets can be classified into three types: 1) real-time VR video, 2) sensory information (temperature, the level of carbon monoxide, etc.), and 3) surrounding information (traffic, risk of the secondary accident nearby, etc.). The first type of information should be real-time. On the other hand, information of the second type is enough to be periodically updated, because the sensing information does not change rapidly over time. Drones of the third type transmit the collected information to the commander centre and control the surrounding traffic and environment. The fleet leaders (high-end drones) can also be classified into three types such that they collect the information from fleet members of the corresponding type and communicate with the command centre. Figure 4-6 depicts the differentiated drone fleets.

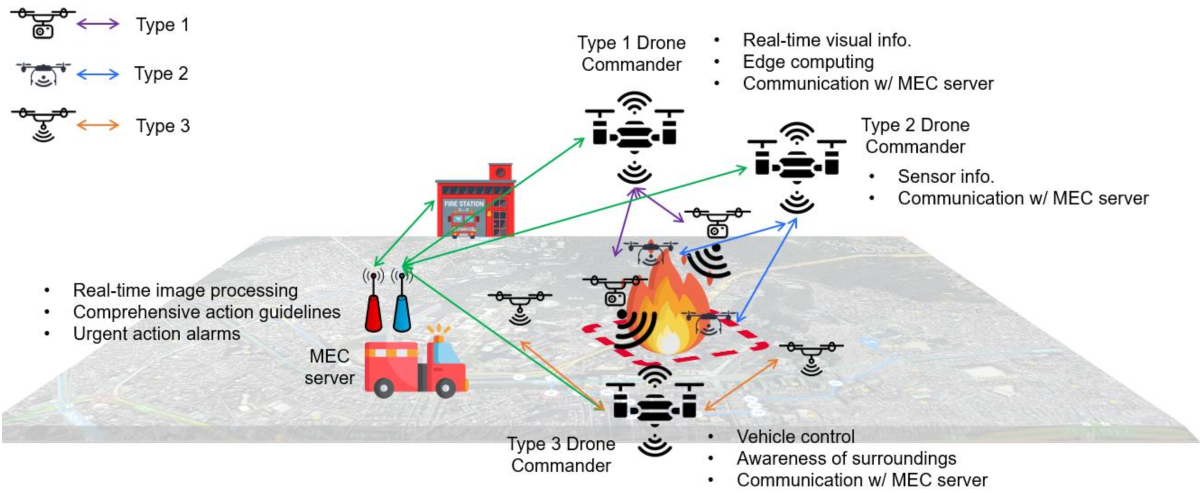

Figure 4-6: Illustration of differentiated drone management for firefighting in urban area

It should be mentioned that the fleet management includes both physical and logical aspects. Since drones are sensitive to the weight and battery consumption, some drones may have limited functionalities. We can think of a drone with high resolution camera but lacking other sensors, and other drones with opposite capabilities. For this case, it is reasonable that the physical limitation determines which fleet the drone should be in. As for a versatile multi-purpose drone, it is possible that a single drone is involved in multiple fleets, performing multi-tasking to deal with the requirements of the fleets. However, it is also possible that such a multi-purpose drone participates only in a fleet at a time because the processing power and remaining battery are not enough for conducting multiple tasks. It is likely that each fleet dynamically changes its fleet members depending on the location, physical specification, processing power, and battery life of the drones. Therefore, elaborated formation, radio resource, and battery management algorithms will be required for maintaining the differentiated drone fleets. Coordination between the fleets is another requirement.

Different fleet types also have different technical challenges, and thus different solution approaches. Here, the real-time video processing and transmission (type 1) is definitely most demanding. For this goal, the two-tier edge computing system, consisting of fleet members, fleet leaders, and the MEC server could be exploited. Owing to very harsh environments at the incident site, it is expected that high-definition video delivery is hardly achievable. The fleet members transmit the collected visual information to its fleet leader, and the fleet leader aggregates all the received information and then transmits it to the MEC server. Both the fleet leader and the MEC server have an ability to improve the quality of images by using the technique of super-resolution, but computing capacity of the fleet leader is limited compared to that of the MEC server. Thus, the MEC server could process the received images and provide the high-definition video to firefighters. The video from the MEC server has higher quality than computed at the fleet leader but its delay could be longer. Distributed computing at the fleet leader is also available to reduce the transmission delay, and furthermore, the fleet members can directly transmit their visual information to firefighters without improving the quality if it is very urgent.

Different from type 1, drones of type 2 periodically report sensing information to their fleet leaders and/or the server. Since sensing information, e.g., temperature, carbon monoxide level, does not change rapidly over time compared to visual information, type 2 operation is less delay-sensitive than type 1, but higher reliability would be required instead. Since drones of type 3 are communicating with surrounding vehicles and units, they could be relatively distant from drones of type 1 and 2. Therefore, interference with drones of type 1 and 2 may not need to be considered. However, coordination with the cellular infrastructure and its users (people and vehicles) would be a technical requirement.

4.2.2.2 Identified requirements

Detailed descriptions of the requirements are categorized into: operational, functional and technical requirements.

Operational requirements

- The drones take at least one of main roles as follows: 1) real-time image collection, 2) sensory information collection, and 3) monitoring and controlling the surrounding environments, e.g., vehicular traffic.
- The drones are aware of their types, grouping information and fleet leaders while interacting with the people near and inside the dangerous site and providing them necessary information.
- The fleet leader has the ability to deliver the instructions of the incident commander to fleet members as well as to relay the information of the incidental site collected by fleet members to the incident commander.
- The incident commander should have the capability to dynamically group the fleet members according to their types depending on the incidental environments as well as to receive and process real-time streamed video of the fire scene.

Functional requirements

- Changes in mission status of each agent due to unforeseen events are updated to its leader immediately to adjust drone types and groupings as well as to reallocate the tasks.
- The incident commander is aware of every drone’s position, battery charge, the importance of information, etc., and dynamically assigns the specific-type missions to all drones.
- The drones perform tasks of their types according to the dynamic fleet control policy of the incident commander.

Technical requirements

- The optimization of task type assignment on the drones depending on their locations, battery charges, communication environments, etc.
- The optimization of computing resources with respect to the computing/latency hierarchy of the different agents as well as battery charges of every drone in the incidental site.
- Two-tier communication among the incident commander, the fleet leader, and the fleet members
- Communication among the fleet leaders of different types
- Communication among drones, MEC, and the firefighters for the exchange of important information from the fire scene and command messages

4.2.2.3 Identified research challenges

From the functional and technical requirements, various research challenges can be identified. These include, but are not limited to:

Awareness of drone locations and battery charges

- Locations and battery charges of the drones are necessary for dynamic fleet control and radio resource optimization. The incident commander should receive all information of drone locations and battery charges and high reliability is required for all those links.

Dynamic fleet control and task type assignment

- The drones take at least one of main roles as follows: 1) real-time image collection, 2) sensory information collection, and 3) monitoring and controlling the surrounding environments, e.g., vehicular traffic. Depending on the location, the information of certain type would be better for the drones to collect than the information of 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.

Trade-off between communication and computing

- In this scenario, the two-tier network is constructed including the incident commander, the fleet leaders, and the fleet members. The computing capacity and their power resources are different. 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 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 processing task is required.

AI-assisted image processing

- The 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, the super-resolution technique is required to obtain the high-definition real-time images of the incidental site.

AI-assisted drone path control

- The real-time images should be collected at various angles and distances to provide the appropriate instructions to firefighters at the incidental site. For this goal, the incident commander needs to control the locations of the drones. Also, there are so many blockages in the fire scene, so the drones are better to find the LOS channel to provide the clear visual information. Especially when mmWave network is used, high reliability could be also provided. Therefore, the drones need techniques to detect its pathway based on learning methods and to move to find the LOS channels.

4.3 Summary of use cases

The use cases identified in this deliverable can be summarized in Table 4-2, Table 4-3, Table 4-4, and Table 4-5 as follows:

Table 4-2: Summary of use case A1

Placement of communication and computing for forest firefighting	
Use case aspects	Descriptions
What does this use case try to achieve?	This use case aims to identify necessary communication and computing functions for scenario A and decide the placement of these functions
What are preconditions for the use case?	The system has access to radio spectrum which is not interfered by other users.
How is it done today, and what is new?	Firefighting teams have a lack of location information. Also, incident commander does not have any detailed information about the fire scene.
What differences will this use case make?	The incident commander will be able to make accurate and timely decisions based on real-time VR information, and the firefighting team will be able to perform the operations more efficiently and safely based on precise location information and relevant commands.

Table 4-3: Summary of use case A2

Network slice management for forest firefighting	
Use case aspects	Descriptions
What does this use case try to achieve?	Deliver network slices that guarantee different network requirements to various communication types i.e. URLLC, Video Communications, Management communications, etc.
What are preconditions for the use case?	SDN capable switches, high bandwidth and reliable radio links.
How is it done today, and what is new?	Today, the traffic requirements are met with static traffic marking. We propose dynamic allocation of resources and network slice management to isolate different communication types and guarantee the network requirements.
What differences will this use case make?	Ensure network can fulfil the requirements for high reliable and low latency communications as well as other type of communications in the same infrastructure.

Table 4-4: Summary of use case B1

UAV-assisted preparatory measures for smart urban firefighting	
Use case aspects	Descriptions
What does this use case try to achieve?	The main goal of the use case is to elucidate each possible variation, potential challenges of wireless network specifically for a fire situation in urban areas. This use case also aims to clarify a practicability of an unmanned aerial vehicle in a fire scene.
What are preconditions for the use case?	Firefighting teams have accessibility to 5G infrastructures that supports immersive information processing through stable radio links.
How is it done today, and what is new?	Current firefighting system has inherent communication risks related to limitations of the current wireless communication technologies.
What differences will this use case make?	5G wireless communication system will allow effective radio communication and immersive data processing especially for a fire situation in urban areas.

Table 4-5: Summary of use case B2

Differentiated UAV fleet management for smart urban firefighting	
Use case aspects	Descriptions
What does this use case try to achieve?	Dynamic fleet control depending on locations and battery charges of the drones, channel environments, etc., under the optimized adjustments of computation (image processing) and communication loads.
What are preconditions for the use case?	Radio spectrum for communications among drones, firefighters, and the incidental commander which do not interfere with each other (orthogonal spectrums, beam directivity of mmWave, etc.) Full knowledge of locations and battery charges of the drones at the incidental commander side
How is it done today, and what is new?	Direct communications between firefighters and the incidental commander at the fire scene are very difficult. Even though UAVs are considered to help firefighters today, assignments of the specific missions to every UAV, location selections of UAVs, and power control depending on battery charges should be studied.
What differences will this use case make?	The incident commander will be able to construct the two-tier network including the fleet leader and fleet members, to assign the task types to the fleet members, and to adjust computation and communication loads.

Various requirements have been identified in each use case. From a high-level, these requirements can be simplified, and the labelled. A summary of the requirements for the use cases is shown in Table 4-6.

Table 4-6: Summary of requirements in the use cases

Req. ID	Type	Description of the requirement	Relevant use cases
RQ-O1	Operational	Localization of the machines and firefighters	A1, B1, B2
RQ-O2	Operational	Situation awareness of the machines	A1, B1, B2
RQ-O3	Operational	Real-time VR video available for incident commander	A1, B1
RQ-O4	Operational	Real-time AR video available for firefighters	A1
RQ-O5	Operational	Network slicing support	A2,
RQ-O6	Operational	Interaction of drones with people and cars	B1,
RQ-F1	Functional	Visual crowd-sensing of the videos	A1, B1
RQ-F2	Functional	Real-time VR and AR video processing	A1, B1
RQ-F3	Functional	Software defined networking at the network switches	B2
RQ-F4	Functional	Dynamic mission allocation to UAV fleet members	B1, B2
RQ-T1	Technical	Communications between the actors	ALL
RQ-T2	Technical	Wireless backhaul connectivity	A1, A2
RQ-T3	Technical	Double connectivity for reliability	A2
RQ-T4	Technical	Dynamic handover	A1
RQ-T5	Technical	Optimization of computing resources	B1, B2
RQ-T6	Technical	Optimization of mission and task assignment	B2

5 KPIs for PriMO-5G use cases

In this section, we describe a high-level framework of defining service-oriented KPIs. In 5G, the design of KPIs is not only static as was in previous generations but can also be highly dynamic in the presence of network slicing and orchestration. Furthermore, various AI-assisted networking and application processing algorithms in the course of E2E services will add more dynamicity. We introduce a hierarchical KPI framework where an E2E KPI is divided into domain-level KPIs and further down to specific KPIs in each domain. Then, we explain methods of defining KPIs in different domains.

5.1 Service-oriented KPI framework

5.1.1 E2E service design

Static service design

The traditional way of designing services has been to consider static requirements of services as a part of network planning. In this approach, one defines what services to run in the network, gathers data about traffic requirements of the services over a time-period, and then defines E2E KPIs for the services, e.g. with respect to latency. When all these input data are in place, a network design which will fulfil all the service and network requirements can be conducted.

Dynamic service design

With 5G, dynamic approach of service design will be supported where services will be defined case by case and dynamically introduced to the network. The dynamic approach of service design is supported by highly advanced management and orchestration solutions which act on different hierarchical levels in the network. The static and dynamic service design approaches are not exclusionary but rather complementary service design approaches for 5G networks.

From a technical point of view, each domain in the network has different ways to support the implementation of the dynamic service definition requirements. For the wireless domain, 5G concepts like slicing and the 5G QoS framework is highly evolved to support advanced dynamic service introduction.

The dynamic service design is supported by a layered service introduction and KPI framework. See Figure 5-1.

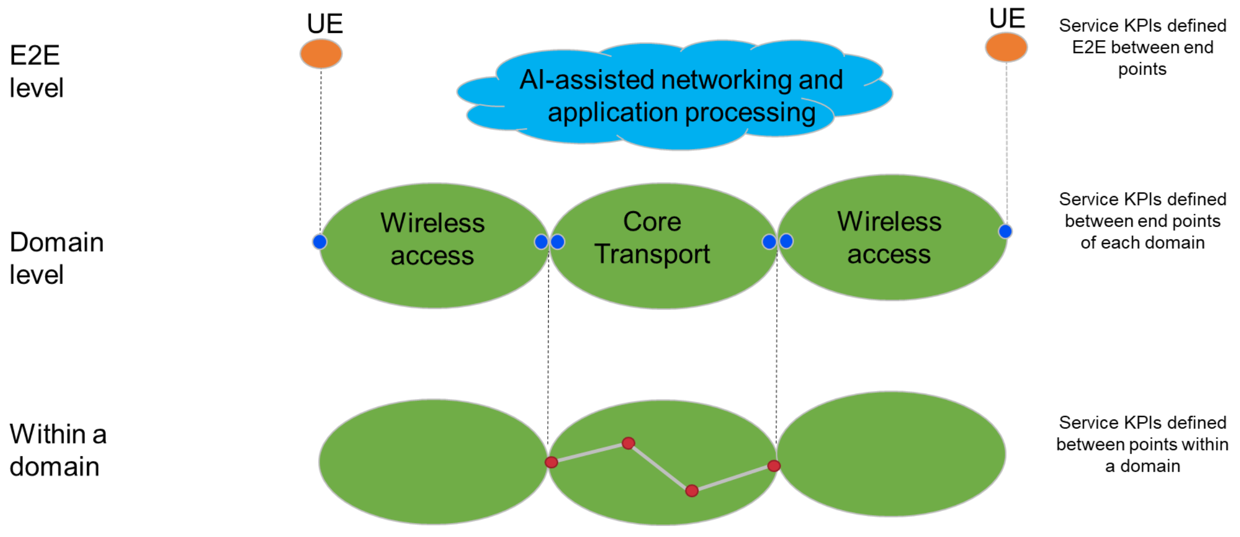

Figure 5-1: Hierarchy of KPIs in different levels

The general approach of the KPI framework 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 domain level can support a highly automated approach of the service introduction.

It should be emphasized that the E2E KPIs are heavily affected by the computing algorithms dealing with the applications and the computing power that the nodes in the E2E architecture have. Consider a real-time video service delivery as an example. Video 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.

5.1.2 Key services of PriMO-5G use cases

From the use cases described in the previous section, the following services have been identified as the key services.

- **Real-time VR/AR video**: the main role of a fleet of UAVs is to collect real-time images of the incidental site. Not only the broad view but also the detailed images, e.g. inside the building fire, are required for the firefighters and the command centre. At different geological locations, UAVs observe the incident site at different angles and directions and transmit the images to the command centre. The centre collects and processes those images to realize the real-time VR video for understanding of the overall disaster situation. Some firefighters can receive real-time AR videos which significantly improve the sight of the firefighters when the visibility is impaired by smokes and obstacles. Sometimes, owing to battery issue, UAVs would not be able to provide the high-definition images. Then, AI-assisted image processing algorithm may be implemented to enhance the image quality.
- **Command messages to control robots and UAVs**: a messaging scheme must be defined for the control centre to send command messages to robots and UAVs. The control centre needs to be able to give commands to each component of UAV separately. For example, there could be command messages to control the movement of a robot (e.g. go forward at 1m/s), to control the camera (e.g., take a still shot), or to control the camera gimbal. Command messages usually take the form of on-demand remote procedure calls, whereas sensory data delivery being periodic data streams. The command messages require very high reliability and low latency, although data rates may not need to be high.
- **Voice connections among the firefighters and the incident commander**: voice is traditional, yet one of the most effective means of communications. Voice connections are much less demanding compared to the real-time videos command messages.
- **Sensory information delivered to the incident commander and the control centre**: sensory information includes the data of the fire scene measured by the robots, UAVs, and the firefighters (e.g. temperature, wind speed, gases, toxic substances, etc.) and the data of the surroundings (e.g. traffic, people's locations, etc.). In most of the cases, the sensory information can be delivered in a periodic manner, and it can tolerate more latency than other services. However, some measurement data, such as an indication of collapse or explosion and a detection of toxic substances, requires the highest priority to be delivered to the command centre.

The E2E services may be supported by sub-services within each domain to fulfil the overall requirements.

5.2 E2E level KPIs

The key services of PriMO-5G use cases have different requirements to the system. KPIs define a set of values against which the requirements can be measured. Many E2E KPIs have been defined within various 5G-PPP phase II projects such as 5G Transformer[25] and 5GCAR[26]. 3GPP and ITU have defined domain and sub-domain level KPIs in 3GPP TR 38.913-f00[27] and ITU-R Report M2410-0[28].

5.2.1 Technical KPIs

Data rate

The E2E system must ensure a minimum required bit rate for the application to function correctly. It corresponds to the user experienced data rate as defined by ITU / 3GPP.

E2E latency

Maximum tolerable elapsed time from the instant a data packet is generated at the source application to the instant it is received by the destination application. This includes the time needed for downlink or uplink and any necessary routing in the infrastructure.

E2E reliability

Maximum tolerable packet loss rate at the application layer within the maximum tolerable E2E latency for that application.

Service deployment time

Duration required for setting up end-to-end logical network slices characterised by respective network level guarantees (such as bandwidth guarantees, E2E latency, reliability...) required for supporting services of that particular vertical sector.

Security

Public safety systems have high demands in security. Different aspects of security are privacy, confidentiality, integrity and authentication.

5.2.2 Operational and functional KPIs

Operational deployment time

When the fire fighters arrive at the site of a fire, the situation is unknown. The highest priority for the incident commander is getting a detailed overview of the situation as fast as possible. Therefore, the deployment time must be reasonably low.

Operation durability

During an incident, the environmental factors can be harsh. The challenges include heat, smoke, wind and rain. A ready-to-use system must be able to withstand these environmental factors.

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[25] Horizon 2020 5G-TRANSFORMER Project, Deliverable D1.1, Report on vertical requirements and use cases http://5g-transformer.eu/wp-content/uploads/2017/12/Report_on_vertical_requirements_and_use_cases.pdf

[26] Horizon 2020 5GCAR project, Deliverable D2.1, 5GCAR Scenarios, Use Cases, Requirements and KPIs https://5gcar.eu/wp-content/uploads/2017/05/5GCAR_D2.1_v1.0.pdf

[27] 3GPP, Technical report on the study on scenarios and requirements for next generation access technologies, TR 38.913, http://www.3gpp.org/ftp/Specs/archive/38_series/38.913/38913-f00.zip

[28] ITU-R, Minimum requirements related to technical performance for IMT-2020 radio interface(s), https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

Position accuracy

Responding to a fire incident requires precise knowledge of the positions of different entities. Not only the position of moving objects is important, but also the position of the fire itself. This KPI defines the maximum positioning error tolerated by the application.

5.3 Defining KPIs in wireless domain

5.3.1 5G QoS framework

The overall QoS framework for 5G is shown below in Figure 5-2:

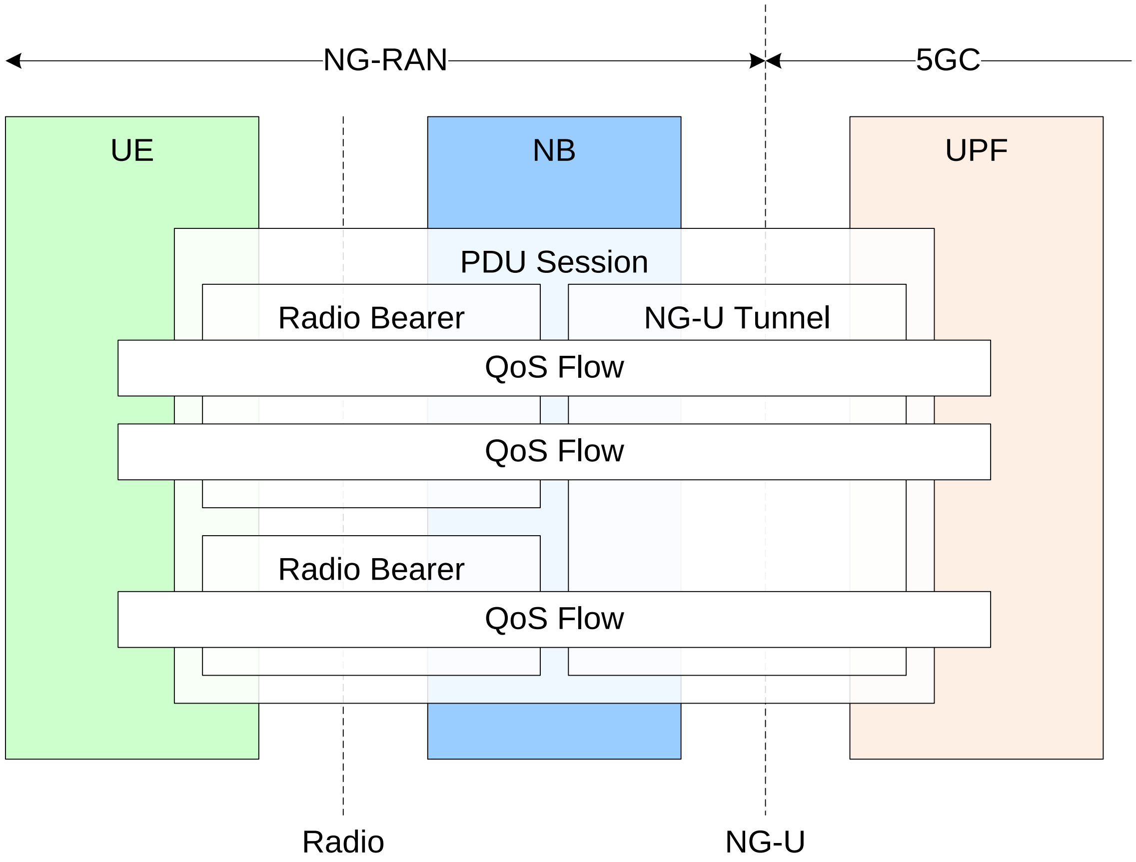

Figure 5-2: 5G QoS framework[29]

The 5G QoS framework covers both the NG RAN and 5GC up to the UPF. Between UE and UPF, 5GC establishes one or more PDU Sessions. Each PDU Session supports a single PDU Session type: IPv4, IPv6, IPv4v6, Ethernet, and Unstructured. Within a PDU session one or several QoS flows can be established. Each QoS flow is identified by a QFI. QoS flows are supported by tunnels on NG-RAN and 5GC. Between NB and UPF, a NG-U tunnel is defined, and between UE and NB, one or several radio bearers are defined. The NG-RAN establishes at least one DRB together with the PDU session and additional DRB(s) for QoS flow(s) of that PDU session can be subsequently configured. The NG-RAN

[29] Source: 3GPP, Technical specification on NR; Overall description; Stage-2, TS 38.300, http://www.3gpp.org/dynareport/38300.htm

maps packets belonging to different PDU sessions to different DRBs.

5.3.2 QFI values framework

3GPP defines the QoS framework for 5G in set of documents, including the QFI values framework. A good description of the QFI values framework can be found in 3GPP TS 23.501[30].

A QoS flow is supported by a framework of QFI values that are defined by:

- Resource Type (GBR, Delay critical GBR or Non-GBR);
- Priority level;
- Packet Delay Budget;
- Packet Error Rate;
- Averaging window (for GBR and Delay-critical GBR resource type only);
- Maximum Data Burst Volume (for Delay-critical GBR resource type only).

A 5QI is a scalar that is used as a reference to 5G QoS characteristics i.e. access node-specific parameters that control QoS forwarding treatment for the QoS Flow. The 5G QoS characteristics for pre-configured 5QI values are pre-configured in the AN. Standardized or pre-configured 5G QoS characteristics, are indicated through the 5QI value, and are not signalled on any interface, unless certain 5G QoS characteristics are modified. The 5G QoS characteristics for QoS flows with dynamically assigned 5QI are signalled as part of the QoS profile.

3GPP has standardized a set of 5QI values according to the Table 5-1 below:

Table 5-1: 5G standardized 5QI values[31]

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)

30 3GPP, Technical specification on System architecture for the 5G System (5GS), TS 23.501, http://www.3gpp.org/DynaReport/23501.htm

31 Source: 3GPP, Technical specification on System architecture for the 5G System (5GS), TS 23.501, Section 5.7.4.

65		7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75		25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6		60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive
9		90					video, etc.)
69		5	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
82	Delay Critical GBR	19	10 ms (NOTE 4)	10^{-4}	255 bytes	2000 ms	Discrete Automation (see TS 22.261)
83		22	10 ms (NOTE 4)	10^{-4}	1358 bytes (NOTE 3)	2000 ms	Discrete Automation (see TS 22.261)
84		24	30 ms (NOTE 6)	10^{-5}	1354 bytes	2000 ms	Intelligent transport systems (see TS 22.261)
85		21	5 ms (NOTE 5)	10^{-5}	255 bytes	2000 ms	Electricity Distribution- high voltage (see TS 22.261)

5.3.3 Initial analysis of wireless domain KPIs

Based on the overall definition of the components of the firefighting communication system in Section

3 and the use cases in Section 4, an analysis was made on the needed services per node point, the functions at each node point, and the 5QI value needed for each service.

Below follows a table of the analysis. See Table 5-2. Note that the node types and 5QI values in the table are the result of an initial analysis which indicates one of the possible combinations. Note that the table should not be considered unique or definitive values. Further refinement should be made with the progress in the technical WPs of the project.

Table 5-2: PriMO-5G wireless domain KPIs based on 5QI

5QI Value	Services	Node type Needed functions	Node type
1	UE voice traffic	UE	Fire trucks
			Firefighter
3	Inter swarm radio communication	RF, (R)AN	Video drones
			Public safety drones
6	Local application processing of drone services	Compute, application	Fire trucks
	Small command control centre	Application, Compute, IAP, UPF, BFF, RF (R)AN	
7	Video traffic	UE or more advanced solution	Video drones
			Public Safety drones
			Fire trucks
			Firefighters
			Public safety robots
69	Control traffic towards drone	Application, Compute, UE (CPE)	Video drones
		Application, Compute,	Public Safety drones
	Relay control traffic towards drone	Relay point	Fire trucks
75	Inter swarm radio communication	RF, (R)AN	Video drones
			Public Safety drones
80	Video traffic	UE or more advanced solution	Video drones
			Public Safety drones
			Fire trucks
			Firefighters
			Public safety robots
	Robot control	Application, Compute, IAP, UPF, BFF, R(AN)	Fire trucks
		UE	Public safety robots

Recall Figure 3-2 which illustrates the components of a public safety communication system. Based on Figure 3-2, the required functions from Table 5-2 are depicted in Figure 5-3.

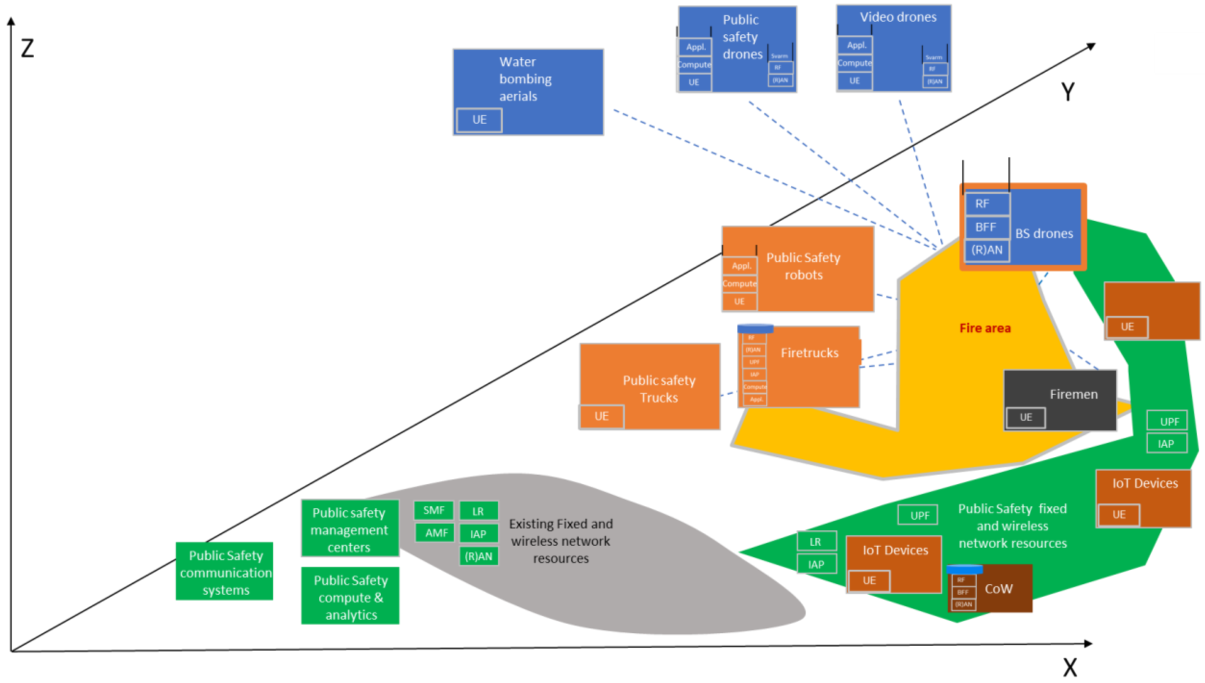

Figure 5-3: Nodes and needed functions to provide services as described in Table 5-2

5.3.4 5QI value consolidation across services and node types

Based on the 5QI value consolidation as shown on the Table 5-2, the Table 5-3 below gives an overview which values need to be taken into account for the QoS characteristics in order to fulfill the QoS requirements from a communications link view point.

- Resource Type (GBR, Delay critical GBR or Non-GBR), where GBR is guaranteed bit rate.
- Priority level;
- Packet Delay Budget;
- Packet Error Rate;
- Averaging window (for GBR and Delay-critical GBR resource type only);
- Maximum Data Burst Volume (for Delay-critical GBR resource type only).

Table 5-3: 5QI values to be considered after initial analysis

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
75		25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
6	Non-GBR	60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming), TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
69		5	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality

5.3.5 Radio access network KPIs

The 3GPP technical report 38913-f00 [32] collects deployment scenarios and scenario-specific requirements that 3GPP identified in order to fulfil IMT-2020 requirements defined by ITU in ITU-R Report M2410-0[33]. More specifically, in Chapter 7 of 38913-f00, KPIs are derived for the radio access network. The KPIs as listed in the Table 5-4 below have been identified to consider on PriMO-5G radio access network in order to fulfil the QoS framework aspects mentioned before.

[32] 3GPP, Technical report on the study on scenarios and requirements for next generation access technologies, TR.38.913, http://www.3gpp.org/ftp/Specs/archive/38_series/38.913/38913-f00.zip

[33] ITU-R, Minimum requirements related to technical performance for IMT-2020 radio interface(s), https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

Table 5-4: Radio access network related KPIs relevant to fulfil PriMO-5G QoS requirements

KPI	Definition
Peak data rate	Peak data rate is the highest theoretical data rate which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e., excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times). [Sec 7.1 of 3GPP TR 38913-f00]
Bandwidth	Bandwidth means the maximal aggregated total system bandwidth. It may be supported by single or multiple RF carriers. [Sec 7.3 of 3GPP TR 38913-f00]
Control plane latency	Control plane latency refers to the time to move from a battery efficient state (e.g., IDLE) to start of continuous data transfer (e.g., ACTIVE)." [Sec 7.4 of 3GPP TR 38913-f00]
User plane latency	The time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by DRX. [Sec 7.5 of3GPP TR 38913.f00]
Reliability	Reliability can be evaluated by the success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a certain channel quality (e.g., coverage-edge). [Sec 7.9 of 3GPP TR 38913-f00]
User experienced data rate	For non-full buffer traffic, user experienced data rate is the 5%-percentile (5%) of the user throughput. User throughput (during active time) is defined as the size of a burst divided by the time between the arrival of the first packet of a burst and the reception of the last packet of the burst. For full buffer traffic, user experienced data rate is calculated as: user experienced data rate = 5% user spectrum efficiency × bandwidth [Sec 7.15 of 3GPP TR 38913-f00]
Mobility	Mobility means the maximum user speed at which a defined QoS can be achieved (in km/h). [Sec 7.18 of 3GPP TR 38913-f00]

Concrete values for the KPIs defined in **Error! Reference source not found.** will be determined in c ollaboration with WP1, WP2 WP3 as well as WP5 following the iterative system design process as described in Section **Error! Reference source not found.**.

The 5G NR specification (Rel. 15) supports a variety of different numerologies and frame structures allowing the use in heterogeneous deployment scenarios. For example, different bandwidth modes are possible for one single component carrier ranging from 5, 10, 20, …, 100 MHz up to 400 MHz. Depending on the FFT size for each bandwidth a certain symbol duration (and subcarrier bandwidth) and consequently a slot duration can be achieved whereas each slot consists of 14 symbols[34]. These values can be treated as a baseline for the described iterative design process. Considering for example a bandwidth of 100 MHz and an FFT size of 4096, a data rate of up to 450 Mbps[35] would be possible. For a sub-6GHz (frequency range 1) system higher data rates could be achieved by:

- Increasing the overall transmission bandwidth to up to 400 MHz utilizing carrier aggregation
- Using up to 8 MIMO layers

[34] See also 3GPP TS 38.211 for more detailed information.

[35] 1x Component Carrier, 1x MIMO Layer, 64-QAM

- Using a modulation order of up to 256-QAM

Similarly, for an above 24 GHz (frequency range 2) higher data rates could be achieved by:

- Using higher bandwidth mode up to 400 MHz
- Increasing the overall transmission bandwidth to up to 1200 MHz utilizing carrier aggregation
- Using a modulation order of up to 64-QAM

A final selection of appropriate values will be done once the end-to-end PriMO-5G network architecture has been established in Task T1.2 of WP1 and the partitioning and functional split has been made based on the available components and their performance.

5.4 Defining KPIs in core and transport domain

5.4.1 The mobile backhaul 5G QoS framework

Generally, mobile backhaul are IP-based networks which operate on a best-effort delivery basis. This means that all traffic has equal priority and equal chance of being delivered in a timely manner. Similarly, when a network becomes congested, all traffic has an equal chance of being dropped. Each vendor has own approach for deploying Quality of Service (QoS). In practice QoS is implemented based on traffic prioritization according to its relative importance and using congestion avoidance to provide priority indexed treatment. QoS can also limit the bandwidth used by a network as well as make network performance more predictable and bandwidth utilization more effective.

The QoS can be implemented using layer 2 (VLANs) or layer 3 (IP ToS or MPLS) technologies. The VLAN QoS is based on traffic tagging which is classified based on a VLAN PRI field while the VLAN untagged traffic classified as best effort (BE).

According to IETF, the two most commonly used QoS architectures are Integrated Service[36] (IntServ) and Differentiated Service[37] (DiffServ). IntServ uses resource reservation (i.e. RSVP protocol) for each flow individually. Every application has to reserve the necessary end-to-end resource in order to ensure the QoS.

DiffServ is an architecture which specifies a simple and scalable mechanism to classify network traffic using different classes to provide the necessary QoS in IP based networks. DiffServ is mainly concerned with classifying incoming packets as they enter in to the local network using different DSCP values. This classification applies to the flow which is defined by 5 tuples, source and destination IP addresses, source and destination ports and transport protocol. Therefore, a flow classified or marked will be treated according its DSCP value.

Implementing QoS requires that switches in the transport network comply with the proposed framework to ensure end to end treatment of the QoS policies. For the DIffserv network QoS policies, the incoming packets must first be classified into the appropriate DiffServ PHB and or PHB scheduling class. The DSCP values are categorized as follows.

- *Expedited Forwarding*[38] (EF): Packets marked with EF values are assumed as higher priority packets. Those packets require low latency, loss, jitter and guaranteed bandwidth traffic.
- *Assured Forwarding*[39] (AF): packets marked with AF values require reliable delivery for

[36] IETF, RFC 1633, Integrated Services Architecture Integrated Services, https://tools.ietf.org/html/rfc1633

[37] IETF, RFC 2475, Architecture for Differentiated Services, https://tools.ietf.org/html/rfc2475

[38] IETF, RFC 3246, An Expedited Forwarding PHB (EF), https://tools.ietf.org/html/rfc3246

[39] IETF, RFC 2597, Assured Forwarding PHB Group, https://tools.ietf.org/html/rfc2597

applications which require low packet drop. Those packets have higher priority than default packets.
- *Default forwarding* (DF): packets which do not have the above markings are assigned as default forwarding packets.

5.4.2 Initial analysis of transport domain KPIs

The radio access has a set of QoS values standardised in 3GPP as shown in Section 5.3.2. These values have to be mapped with equivalent packet tagging applied in the backhaul transport network. Following the definition of the components of the firefighting communication system in Section 3 and the use cases in Section 4, the 5QI values needed for each service requires an equivalent marking in the transport network.

Below follows Table 5-5 where a set of packet tagging could be used as initial analysis which indicates one of the possible combinations[40]. Note that Table 5-5 should not be considered unique or definitive values.

Table 5-5: Initial analysis of mapping between 5GQI and packet tagging

QoS Class	Drop Probability*	PRI	IP DSCP	MPLS EXP	QFI
CS7	.	7	56	6	69
EF	.	6	46	5	80
AF4	AF43	.	38	.	3
	AF42	-	36	.	
	AF41	5	34	-	
AF3	AF33	-	30	.	1
	AF32	-	28	.	
	AF31	4	26	3	
AF2	AF23	-	22	-	75
	AF22	-	20	-	
	AF21	3	18	2	6
AF1	AF13	-	14	-	7
	AF12	-	12	-	
	AF11	-	10	1	
BF	-	2,1,0	0	0	

*To enforce the QoS class in the network requires an active queue management algorithm such as Random Early Drop (RED) that will result in different dropping probabilities for each QoS class. The queuing system can configure different congestion level thresholds. When the smoothed congestion level is below the first threshold, no packets of the relevant precedence are discarded. When the smoothed congestion level is between the first and the second threshold packets are discarded with linearly increasing

[40] For the definition of the terminology in the table, refer to S. Alvarez, QoS for IP/MPLS Networks, Cisco Press, 2006.

probability, ranging from zero to a configurable value reached just prior to the second threshold. When the smoothed congestion level is above the second threshold, packets of the relevant precedence are discarded with 100% probability[41].

5.4.3 Advanced management of QoS

In 4G, the mobile backhaul network have fulfilled the traffic requirements based on over-dimensioning and pre-provisioning that ensure enough capacity for best-effort IP based networks. However, 5G mobile networks aim at new features like URLLC. 5G brings network slicing which 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 in order 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. Thus, the pre-configured 5QI in the radio interface which are then mapped statically into DCSP traffic marking as proposed in Table 5.5 is not sufficient for 5G networks.

The mobile operator can over-dimension and pre-provision the network with the required slices for URLLC and the required network resources can be reserved to isolate the URLLC traffic to its own slice. Thus, pre-provisioning allows us to tailor the network resources to meet the traffic requirements in the best possible way knowing user needs in advance.

However, the network needs to dynamically re-allocate the available resources to include new slices without disrupting existing ones. Thus, in case of un-predictable emergency situations, the network should dynamically re-allocate available resources to support new ad-hoc URLLC or other types of slices. Moreover, in case the M2M traffic increases drastically due to their scheduled based transmission patterns, the M2M slice must be isolated from others.

Therefore, the network must re-allocate available resources dynamically to guarantee URLLC requirements for the new slice without disrupting existing slices. The network slices would be used to isolate unpredictable peaks of traffic e.g. M2M from URLLC or best effort traffic. Therefore, a more advanced traffic management is required to adapt the QoS for each traffic based on the network conditions and available resources. Thus, network slicing enhanced with ML solutions can be adopted to monitor and set new traffic priorities using SDN technologies.

41 IETF, RFC 2687, PPP in a Real-time Oriented HDLC-like Framing, https://tools.ietf.org/html/rfc2687

6 Conclusions

The main objective of this deliverable is to describe the selected scenarios and use cases which lay foundation to the technical work packages of the PriMO-5G project. We started by clarifying the definition of terminology such as requirement, scenario, system, use case, which are often used without care. Then, we described a scenario-based system design process. The project will adopt the process throughout its lifetime.

We consider firefighting to be one of the key areas where immersive video services with moving objects, particularly UAVs, can make the operations much safer and more efficient. Thus, we focused on the firefighting and provided an overview of the governance of fires. Then, components of and requirements for public safety communication systems for fire situations were listed and discussed.

We selected two representative scenarios: one for forest fire in rural areas and the other for smart firefighting in urban areas. For each scenario, actors have been defined, and the interactions between the actors are described. The scenarios are augmented by the use cases which depict further details about functional and technical aspects.

As for KPIs, we focused on a high-level framework of defining service-oriented KPIs. We adopted a hierarchical approach where an end-to-end KPI is divided into domain-level KPIs, and then down to specific KPIs at each domain. We provide methods of defining domain level KPIs and an initial analysis of them.

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