Trialing solutions for Security & Safety, Infrastructure, and Transportation, Supported By Smart Networks Beyond 5G

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***Abstract*—TrialsNet is a project dedicated to enhancing European urban ecosystems through a variety of innovative use cases in domains including Security and Safety, Infrastructure, and Transportation. These use cases are being implemented across different clusters in Italy, Spain, Greece, and Romania, involving real users. This paper provides an overview of the diverse use cases, and of the corresponding network solutions, which leverage advanced functionalities like dynamic slicing management, NFV, MEC, AI/ML, and more. The project aims to identify network limitations, optimize infrastructure, and define new requirements for next-generation mobile networks. Ultimately, TrialsNet seeks to improve urban livability by driving advancements across multiple domains.**

***Index Terms*—B5G, Large-scale trials, Safety and Security, Infrastructure, Transportation**

I. Introduction

5G was designed to support a broad array of network services. Indeed, it can handle various services, thanks to technologies like network slicing and Service-Based Architecture (SBA) in its core. Commercial deployments and trials conducted by projects such as 5G-PPP [1] have shown the versatility and readiness of the technology to meet the key performance indicators (KPIs) necessary for demanding applications. However, the broader impact of 5G on human society and its potential to create a deeper impact compared to previous network generations remains to be seen.

To assess how 5G and future technologies might enhance people's quality of life, the United Nations' Sustainable Development Goal 11 (UN-SDG11) [2] serves as a benchmark. UN-SDG11 emphasizes the importance of inclusive, safe, resilient, and sustainable cities. With over half of the global population currently living in urban areas and projections suggesting this will rise to 68% by 2050 [3], cities will play a crucial role in economic, social, environmental, and global developments. To manage this population growth, infrastructure investment will need to double by 2040 [4]. In this context, efforts are underway to make cities safe, affordable, and sustainable for all, aiming to prevent issues like congestion, sprawl, pollution, and inequality. The concept of Digital or Smart Cities has garnered significant attention. While strides have been made in tackling environmental degradation, traffic congestion, inadequate urban infrastructure, and essential services, further work is needed to fully meet UN-SDG11. Cities should be viewed as urban ecosystems that include human populations, their characteristics, and the biological and physical components around them. Achieving SDG-11 involves optimizing every aspect of this urban ecosystem in a holistic and interconnected manner, promoting economic growth and benefiting both residents and businesses. This will be possible thanks to the realization of advanced infrastructures, applications and services.

In this context, the TrialsNet project https://www.trialsnet.euhttps://www.trialsnet.eu aspires to achieve societal benefits by deploying 5G and beyond applications across diverse Use Cases (UCs) that act as precursors to the 6G ecosystem. These UCs bridge the physical and digital worlds, facilitating the transition to the next generation of mobile networks. They represent extensive trials in fields including infrastructure, transportation, and

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security and safety. They are fully described in [5], while we present in this paper (Sec. II to VII) their main characteristics, the corresponding network architecture of reference and the correlated large scale trialing activity.

II. UC1: Smart Crowd Monitoring in Madrid

This UC is a comprehensive trial aimed at ensuring the safety and security of individuals within densely populated areas, particularly during large-scale events that will be held in Madrid's sports venues, during December 2024. By leveraging cutting-edge technology, this use case addresses security risks inherent in such gatherings, including crowd management, violence, vandalism, and suspicious activities such as loitering or abandoned items. The scope of UC1 Madrid encompasses the deployment of advanced technology solutions to detect and respond to security threats effectively. Surveillance cameras, LiDARs, and AI algorithms form the backbone of the monitoring system, facilitating real-time threat detection and response. Additionally, ground robots equipped with cameras and artificial vision capabilities are utilized for autonomous and remote-controlled security inspections.

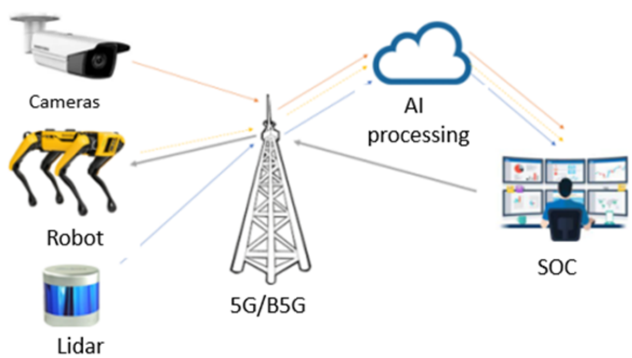

Fig. 1. Smart Crowd Monitoring in Madrid solution (UC1).

A. Network Architecture

5Tonic Laboratory www.5tonic.orgwww.5tonic.org and the 5G/B5G Non-Public Network (NPN) of Ericsson are the main infrastructures to carry out the validation of UC1 trials over B5G network. The Ericsson 5G NPN infrastructure is a distributed 5G Stand-Alone (SA) network. The 5G SA architecture adopts the new concept of Service-Based interfaces. This means that the Network Functions (NFs) that include logic and functionality for processing signaling flows are not interconnected via point-to-point interfaces but instead exposing and making available services to the rest of NFs. Thus, there is a separation that broadens the range of possible locations for the network elements. The RAN and the User Plane Function (UPF) are installed at venue premises, while the rest of components of the 5G Core (5GC), i.e., the control plane components, are running at 5Tonic.

RAN equipment is mid-band (n78 - 3.5 GHz) and Standalone technology. 5G RAN equipment splits the user plane traffic and the control traffic. The use case traffic is directed via the UPF towards the vertical applications. In this way, the user plane traffic remains geographically close to the end user devices, keeping a very low latency.

B. Large Scale Trial

At the 5Tonic lab in Madrid, Ericsson and Prosegur conducted extensive testing activities in October 2023, to evaluate the 5G network's performance using different setups. In the first configuration, the camera test measured throughput and latency for fixed camera connections at various image qualities. The traffic transmission speed was lower than expected without video compression, significantly impacting latency. The LiDAR test measured uplink throughput and revealed lower-than-anticipated traffic but successful data transmission without reaching network saturation. The saturation test involved all devices (robots, LiDARs, and cameras) connected simultaneously, showing network saturation at an uplink throughput of 80 Mbps, leading to congestion. In the second configuration, the Kiiro robot test assessed throughput under various operational modes, reaching the expected 10 Mbps only when fully operational with high-quality video streaming, LiDAR usage, and teleoperation. The tests highlighted the need for improvements in managing saturation and optimizing throughput. Next steps include optimizing the 5G network, implementing a VPN for better integration, testing edge and cloud algorithms for image processing, and further stressing the network with multiple devices to advance B5G capabilities. Further preliminary results are available in [7].

III. UC1: Smart Crowd Monitoring in Iași

This use case is conducted in a large public area in Iași, Romania, focusing on leveraging B5G/6G technologies to enhance situational awareness for key stakeholders in the city. The project aims to integrate various data streams into a unified operational picture, providing real-time insights and actionable intelligence for public safety. The new platform ingests data from an array of cameras placed throughout the city, utilizing robust B5G and Wi-Fi networks to deliver critical information to a public safety monitoring system. The primary focus is on monitoring outdoor public events, specifically on Stefan cel Mare Boulevard, a highly frequented pedestrian area in Iași. The system performs people counting, crowd density and movement dynamics calculations, as well as detecting unusual situations, such as unauthorized vehicles in restricted zones. Special attention is paid to the ethics aspect by implementing technical measures (image blurring, data protection) and administrative measures (no data storage and restricted access in the control room).

A. Network Architecture

The current technical solution of UC1 in Iași is based on the commercial 5G Non-Standalone (NSA) deployment of Orange (ORO) and is undergoing testing activity for the project since October 2023. The Romanian cluster is hosted within ORO's 5G Labs, from both Bucharest and Iași. The Bucharest 5G Lab is located inside the CAMPUS Research

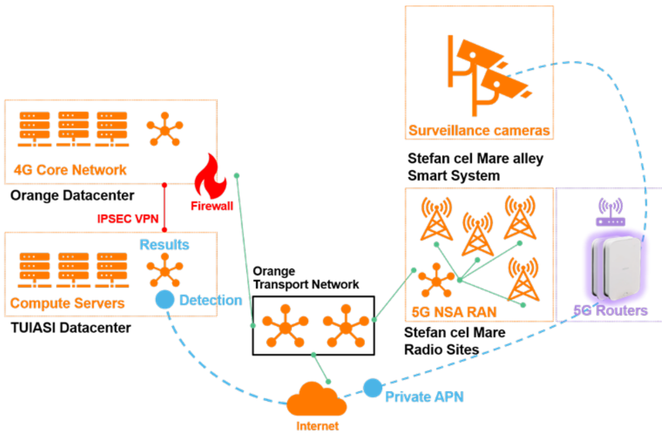

Fig. 2. UC1 in Iași 5G and Edge-Compute final architecture.

Center of UNSTPB and currently implements a full 5G SA infrastructure, comprising 5G RAN, Core, Edge Computing and advanced Software Defined Networking (SDN) elements in the associated datacenter. This architecture utilizes the on-field deployed hardware, including surveillance cameras and Nokia Fastmile 5G14-B 5G routers fitted with specially provisioned SIM cards for the TrialsNet project's private APN that directly connects to ORO's 5G Lab edge computing facility. Video feeds are accessible by Technical University Iași (TUIASI) via an IPsec VPN tunnel linking ORO's Bucharest 5G Lab and TUIASI's network infrastructure. TUIASI's servers host the video analytics application, which performs inference and data visualization, enabling efficient crowd management and enhanced public safety.

B. Large Scale Trial

Tests using 5G-connected surveillance cameras for crowd monitoring aimed to estimate crowd density and detect objects in restricted areas, using pre-trained neural network models integrated into a video analytics platform based on the NVIDIA DeepStream framework. Field tests were conducted directly on-site after camera installation in the summer of 2023. The setup included 5G routers and cameras mounted on lighting poles. Initial lab tests involved calibrating image processing algorithms and developing dashboards for application monitoring. Connectivity tests were also performed from the laboratory command center. Privacy-preserving measures were strictly implemented, ensuring no personal data was monitored or stored. Several field tests were executed by TUIASI and ORO to assess performance across different scenarios such as crowd dynamics, flow directions, and detection of unauthorized access. During peak periods such as the "Sf. Parascheva" religious celebration, network congestion affected throughput, with downlink speeds reaching 130 Mbps against a target of 500 Mbps. However, improvements were observed during the winter holidays fair, indicating variable network performance based on demand/number of participants. Following the network upgrades to outdoor 5G SA by the end of 2024 and the completion of edge-compute infrastructure installations, the next phase will focus on final testing. This includes evaluating uplink/downlink throughput and end-to-end network latency under the new 5G SA environment. Further preliminary results are available in [7].

IV. UC2: Public Infrastructure Assets Management

This use case offers a cutting-edge solution for Proactive Public Infrastructure Assets Management at Athens International Airport (AIA) and public infrastructure provided by DAEM in the Municipality of Athens. Data is collected from security cameras, drones, municipal vehicles, and AGVs, then transmitted using 5G and processed using AI-based algorithms and Deep Learning mechanisms to evaluate the condition of infrastructure assets. Generated alerts and recommendations for maintenance and safety tasks concerning the structural health of buildings, pavements and roads, provide a more efficient and effective proactive management, leading to cost savings and improved operations and services. Augmented Reality (AR) is also used to provide on-site views of assets' blueprints and communicate with remote experts.

A. Network Architecture

The current networking setup of the "Public Assets infrastructure Management" scenario is based on the campus 5G NSA deployment at WINGS labs in Athens and the Commercial 5G network deployed at AIA and DAEM. The Greek cluster is hosted within WINGS's 5G Labs located at WINGS premises in Athens, consisting of a full 5G NSA infrastructure, comprising of 5G RAN, Core and Edge Computing capabilities as well as advanced Network Orchestration and Diagnostics functionalities. This architecture utilizes the lab/field deployed hardware, including cameras deployed on moving vehicles, Autonomous Moving Robots (AMRs) and drones. The cameras on the vehicles transmit using an On-board Unit (OBU) equiped with a 5G connectivity module, while the AMRs and the drones directly transmit to the cloud using a 5G connectivity module. The recorded video feeds as well as the output of the infrastructure damages detection, are accessible through the WINGSPARK+ platform deployed at WINGS local webservers. Another deployment of the platform lies in the Amazon Web Services (AWS) where the developed analytics model performs the inference on each video frame on top of a cluster of GPUs for faster detection. The output is then re-trasmitted to the platform where the users can view the detection output in real-time. This network infrastructure has been used for the initial testing of the solution since October 2023 while the field trials utilizing the commercial 5G are planned for the last quarter of 2024.

B. Large Scale Trial

Two different sets of lab tests were executed for UC2, each one pursuing a different objective [7]. The first set focused on the assessment of the performance of the road model, using both an open and a custom dataset. The resulting pipeline implemented for the testing is depicted in Fig. 3. The second

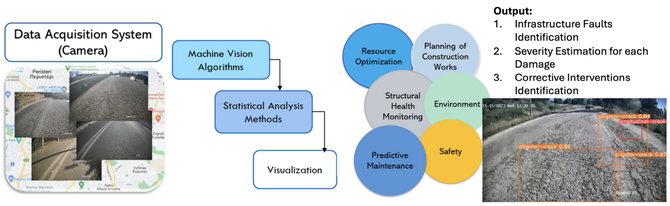

Fig. 3. UC2 - Damage Detection Model Analytics Pipeline. The scope is the assessment of the condition of the infrastructure using video analytics.

set of lab tests focused on assessing the performance of the streaming and restreaming modules of the WINGSPARK+ platform, to test the optimal configurations of the cameras and finally to properly measure KPIs of interest such as application round-trip latency, service reliability, and service availability. Different configurations (using various video encoding formats, resolutions, video quality, framerate and max bitrate) were created using various combinations of the camera's settings to identify the optimal ones for the environment.

Preliminary tests were performed using actual feeds provided by the cameras installed on WINGS corporate vehicles. The tests envisaged optimal positioning of the cameras, confirmed stable video feed from all cameras, and the saving of the actual records both on the SD cards attached to the OBUs, and remotely, on the storage servers both at WINGS premises and AWS deployment. Early demos consisted of videos showcasing the camera feeds, the road damage detection model output as well as the capabilities of the streaming and the restreaming modules developed in the scope of the UC2. Initial KPIs were measured for the road damage detection model and for the streaming and re-streaming module for the deployment at WINGS and the AWS deployment. The software can handle multiple IP cameras and other devices (drones/AMRs) in parallel, detecting 6 different classes of damages and the respective severity score. Then, based on this score the most severe damages are prioritized for inspection. The final large-scale trial will be performed at the beginning of 2025.

V. UC3: Autonomous apron

This use case focuses on the design, implementation and deployment of a solution for the realisation of an autonomous apron scenario at AIA, based on B5G communications aiming to optimize airport operations, such as baggage and cargo ground handling using AMRs. This use case also entails the development of the apron's Digital Twin that allows for real-time depiction of the physical world inside the virtual one, where operators can intervene to remotely control the AMRs in critical situations. Data collected by the sensors onboard the AMRs, such as cameras, LiDARs, and GNSS information are analyzed using AI techniques to provide insights and generate alerts (i.e., in potentially dangerous situations), thus enabling a tight monitoring of the airport activities and an increase of its efficiency.

A. Network Architecture

For the realisation of the autonomous apron use case, a sophisticated architecture that leverages ROS2 and Docker containers has been designed, to enhance the efficiency and scalability of the underlying robotic system. Each robot deployed either in the lab or in the field communicates seamlessly over ROS2, ensuring a standardized and interoperable communication protocol. The robotic layer is containerized using Docker, providing a modular and isolated environment for each robot's software components. To address high-computational demands, an edge compute device has been employed where resource-intensive nodes run, optimizing the robots' processing capabilities. The networking setup of this scenario is based on the campus 5G NSA deployment at WINGS labs in Athens and the Commercial 5G network deployed at AIA as described in detail in Sec. IV.

B. Large Scale Trial

The aim of UC3 testing was to assess the performance of the robot's autonomy and service layer KPI measurement namely the application round-trip latency. The performed testing validated the feasibility of the use case, but also showed the rapid depletion of the robot's battery power [7]. It has been observed that the robot's onboard computer was the primary consumer of battery power. As such, the underlying architecture was changed by transferring most of the robot's computational nodes to the cloud or edge (depending on the scenario). A preliminary analysis showed a dramatic improvement in the robot's battery life and, consequently, its operational autonomy facilitated by the robust capabilities of 5G and 6G networks. New tests will be performed in the last quarter of 2024 using the new architecture in order to re-assess the findings, while the final large-scale trial will be performed at the beginning of 2025.

VI. UC4: Smart Traffic Management

This use case is piloted in the Podu Roș Intersection Area (Iași city, Romanian Cluster) with a focus on enhancing traffic comfort and safety. From a comfort perspective, the traffic flow will be monitored to develop predictive models and suggest adaptive intersection rules to reduce congestion. Safety improvements will primarily protect Vulnerable Road Users (VRUs) by creating a digital traffic model capable of identifying hazardous situations. Utilizing the same infrastructure as UC1 Iași, the new platform ingest data from arrays of sensors and cameras deployed throughout the city, communicating over reliable B5G network, to provide insights and actionable intelligence on the traffic monitoring system. Traffic data is collected in order to provide relevant statistics and identify potential hazards. Given the increasing number of road users and the emergence of new transportation modes, efficient and safe traffic management is crucial.

A. Network Architecture

The current technical infrastructure for UC4 is similar to the one implemented for UC1 Iași. This architecture is

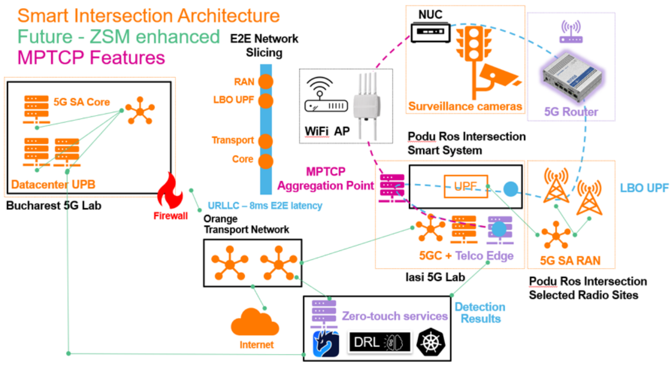

Fig. 4. The network architecture of UC4 with ZSM features.

using ORO's commercial 5G NSA network and a Teltonika RUTX50 5G router (connected to the 5G Lab edge computing infrastructure through a private APN), which aggregates the traffic coming from the surveillance cameras placed in the intersection. Additionally, these cameras are also connected to a Wi-Fi network, which serves as an alternative network to provide supplementary connectivity, ensuring redundancy and resilience in data transmission.

The fully-fledged implementation of UC4 will leverage the Zero-touch Network and Service (ZSM) [9] framework to enhance performance through automated, intelligent network and service orchestration. The ZSM techniques are becoming an indispensable part of Beyond 5G and 6G systems, as they are critical for ensuring the proper functioning of vertical services, by granting the stability and performance of the network. For example, in the context of UC4, mission-critical services that aim to ensure safety of VRUs at the busy intersections, have stringent performance requirements such as ultra-low-latency and extremely high reliability that need to be met regardless of the network load. Therefore, the goal of the ZSM framework is to make proactive service placement and runtime service reconfigurations that will result in reliable vertical service operation. In the case of UC4 deployment (Fig. 4), ZSM will be placed as AI/ML functions that help orchestrators make more sophisticated decisions that in turn result in improved performance and sustainability aspects.

B. Large Scale Trial

UC4 is able to count traffic participants (e.g., pedestrians, vehicles, etc.) and to identify certain traffic violations by monitoring traffic via 5G-connected surveillance cameras at Iași's busiest intersection. Testing activities included both laboratory and field tests [7]. In the laboratory, preliminary calibration tests were performed in a command and monitoring center using pre-trained neural networks within the DeepStream software framework. Field tests began in October 2023 following the installation of a 5G router and camera setup in Iași. These tests evaluated the application's capability to improve traffic management and safety. Despite the shielding effect of the metal technical box, which impacted network performance metrics like throughput and latency, the surveillance streams were processed efficiently. Future improvements include installing an external 5G antenna to enhance performance.

In the next stages, several critical tests and development activities are planned to enhance the UC4. Evaluating the performance of object detection in scenarios with significant partial occlusions, such as traffic jams or peak hours, is a priority, as well as testing the solution under various atmospheric conditions like rain, fog, and varying lighting conditions, particularly contrasting shady and sunny spots. These situations require sophisticated detection capabilities beyond fixed exclusion zones. The software will be enhanced to compute and report individual delays introduced by each component in the video processing pipeline to evaluate the system's total reaction time accurately.

The UC4 application will be integrated into the 5G edge ecosystem by fall 2024, allowing for a new round of field tests from October 2024. These tests will focus on uplink/downlink throughput, end-to-end network latency, edge-computing latency, and application-level latency, which are critical for the use case. Finally, the extensive testing will also include dynamic and advanced orchestration of UC4 application and services, evaluating the impact of ZSM functionalities on the real-time performance of UC4.

VII. UC5: Control Room in Metaverse

UC5 aims to establish a virtual control room in the metaverse for coordinating and training public safety agents during emergencies at large events. The Metaverse Control Room (MCR) will centralize information from field-deployed devices and equipment connected via a 5G network, transmitting data to a cloud server. Sources include streaming cameras, drones, and sensor data. The IoT platform collects and presents this data through a unified interface. The goal is to enhance crisis management by improving decision-making and reducing emergency response times. The trial environment is the events area in Valentino Park (Turin, Italy), used during the 2022 Eurovision Song Contest. The scenario involves a concert where an emergency plan is coordinated among security stakeholders. In an incident, the emergency switchboard (112) contacts required agents who convene in the MCR. Using 5G, they share real-time updates, images, and videos, ensuring effective communication. This use case will test the MCR's effectiveness and 5G network stability in real-world conditions, demonstrating the benefits of a metaverse-based emergency response system.

A. Network Architecture

The Turin site leverages TIM's commercial 5G network for the large-scale trials. This setup is complemented by an advanced VNF orchestration to improve service performance. The infrastructure includes a multi-location environment with extensive commercial coverage and dedicated hardware resources hosted at the edge cloud at Politecnico di Torino (PoliTO). The Turin site architecture is designed to integrate various eXtender Reality (XR) platforms across commercial

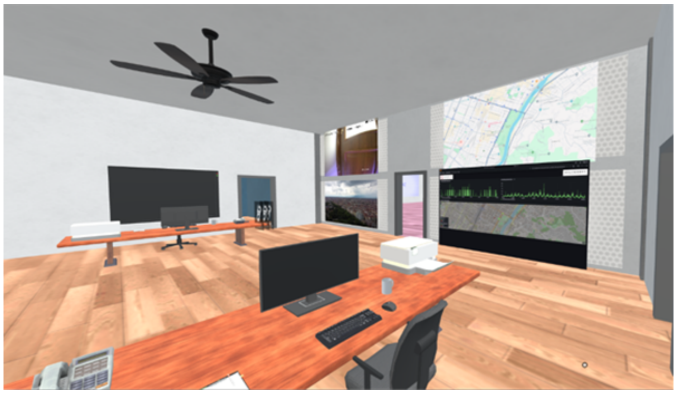

Fig. 5. Metaverse Control Room in UC5

cloud, dedicated servers, and PoliTO's computing infrastructure. The computing infrastructure is managed by Nextworks and supports the backend for this use case. It includes five physical servers for different purposes such as management, compute nodes, and Kubernetes worker nodes. The management server acts as the control hub for the testbed, hosting virtualized environments for VNF orchestration and monitoring. Wi-Fi based sensors have been deployed to estimate the number of people in a transparent way for the users, while the cameras provide high-quality images for situational awareness. The Symphony IoT platform, deployed as a VNF, handles the lifecycle of data from these sensors and integrates with the Mozilla Hub metaverse platform for data visualization. Network and service orchestration is enhanced with an instance of the ZSM framework. VM-based (in OpenStack) and containerized (in Kubernetes) services deployed in the infrastructure are continuously monitored by a combination of a monitoring platform and the capability to instantiate closed-loop functions, constantly assessing service parameters based on targets and goals.

B. Large Scale Trial

Tests aimed to integrate a metaverse system for Turin's safety and security agents, starting with a lab test on a streaming video camera using TIM's 5G network. Conducted at Crossmedia Europe's lab in Turin, the test measured KPIs such as bitrate and latency, using a Hikvision camera streaming to a PC simulating Mozilla Hubs [7]. The setup used WebSockets over HTTPS and the H.264 codec for optimal video quality. Network analysis via Wireshark at 15fps and 25fps indicated that video streams required 16Mbps, with HUBS operations adding 2Mbps, totaling 18Mbps per device. These measurements were adequate for small to medium events but insufficient for larger events with more cameras and agents. A preliminary MCR demo showcased capabilities like image and video uploads, sensor data integration, and live video feeds to stakeholders from emergency services during the second Design Thinking+ meeting in Turin. Security agents use priority SIM cards on the 5G network, supporting up to 25 agents and two cameras for medium events, but only 10 agents for larger events, indicating a need for enhanced connectivity. Future steps involve field tests with a streaming camera, drone, and 5-6 users to determine 5G network limits. These trials will measure downlink and uplink throughputs and service reliability to guide network capacity enhancements. The goal is to ensure robust connectivity for emergency response personnel during large-scale events, preventing network saturation and ensuring seamless operations. A final large-scale trial is foreseen for the end of 2024.

VIII. Conclusion

In this paper we presented different use cases, developed in the context of the TrialsNet project, which contribute to societal benefits, leveraging a 5G and beyond network infrastructures. For each use case, we presented their reference architecture, preliminary results, trialing plan and the advancement status.

Overall, the presented UCs are based on network features going beyond B5G, requiring a set of advanced capabilities to enhance performance and sustainability. This analysis helps to understand the limitations of the current technologies, highlighting the enhancements that need to be made to fulfil the UC requirements. Furthermore, the global view of the security & safety, infrastructure and transportation vertical offered by the composition of the presented UCs, provides insights into the design of similar large-scale trials, on the possible problems that can be found and corresponding solutions, as well as on the key aspects to be kept into acount.

Acknowledgments

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