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TEZE: A System to Enhance Safety in Highway Tunnels as a New Smartphone-Based Emergency Call Paradigm

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Abstract: In the European Union, the eCall system has been mandatory since 31 March 2018. The system enabled a significant increase in safety on roads and highways, making help faster in the event of an accident. However, based on circuit-switched 2G/3G communications and an onboard device called IVS, it is generally unavailable on legacy vehicles. Some of its limitations tend to be remedied by the future NG eCall based on 4G/5G packet-switched communications. This paper discusses why the IVS may be an Achilles' heel of any future IVS-based eCall and analyzes the advantages of a smartphone-based system. The TEZE system, starting to be implemented and installed in Italian highway tunnels, is one first general-purpose safety system, allowing highly reliable smartphone-based emergency calls. It is based on a dedicated low-cost ground infrastructure that allows monitoring of the availability of emergency call service through the mobile radio networks of the operators present inside a tunnel. The system complies with the ISO/IEC 30141:2018 reference standard. Identifying functional/non-functional requirements and their verification criteria provides an overall validation of the analyzed system. The TEZE system has been implemented and tested on the field. We report and comment on some experimental results. The paper also examines some key functionalities for vehicular services that can be implemented in an integrated system based on smartphones and heterogeneous networks.

Keywords: NG eCall; road security; cellular communications; heterogeneous networks; smartphone

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1. Introduction

With Regulation 2015/758 of the European Parliament and Council of 29 April 2015, to improve road safety, the European Union made a pan-European in-vehicle emergency call (eCall) system mandatory as of 31 March 2018. The eCall system opens an emergency session from the In-Vehicle System (IVS)—a device built into the vehicle, car or van—to a Public Safety Answering Point (PSAP) by initiating a voice call between the vehicle and the PSAP and sending a minimum set of data (MSD) in voice band (Figure 1). Based on the 2G(GSM)/3G(UMTS) circuit-switched (CS) standard available almost everywhere, the eCall service has virtually universal coverage in Europe.

In-band MSD transmission in CS-mode occupies the circuit for about 5 s before eCall voice call initiation. A vehicle's passenger compartment button can activate the in-vehicle device by sending a recorded message in the local language to the unified European emergency number (112). In the event of a traffic accident, if the driver and passengers cannot make the call, IVS works automatically. The MSD data format includes the exact location of the crashed vehicle, derived from a GNSS (Global Navigation Satellite System), such as GPS or Galileo. The MSD data format also includes the time, direction of travel, number of passengers, number of airbags deployed, driver's state of consciousness and the fuel used to power the car [1,2].

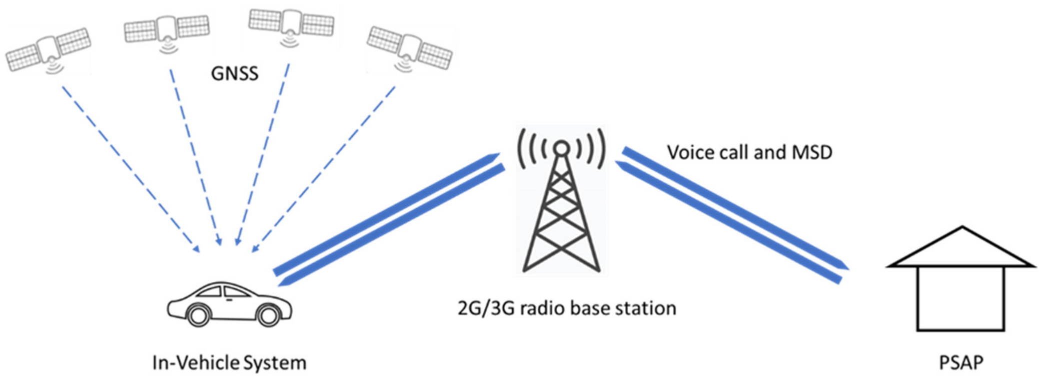


Figure 1. Pan-European eCall system.

According to statistics, the average age of used cars for sale in Italy is about 7–8 years, and they often have two owners in their life cycle. They are typically on the road for about 15 years. Two out of three cars are more than six years old, while 41 percent are more than nine years old. The decline of unequipped cars is slow, and they can be expected to circulate in European road networks for many years. In fact, according to some estimates, 100 percent eCall penetration could be reached by 2035.

However, European mobile network operators (MNOs) have already started the UMTS decommissioning (in Italy, it is underway as of 13 June 2022). They also announced that they will phase out GSM networks in the current decade to replace them by 2030–2035 (end of service) with the infrastructure of the more spectrally efficient 4G/5G systems. An IP Multimedia Subsystem (IMS) emergency call mode for packet-switched (PS) networks at 4G(LTE)/5G standards will replace the current 112 emergency call mode. To facilitate the integration of mobile communications with the Internet, IMS uses IETF protocols, including Session Initiation Protocol (SIP), for session signaling and negotiation.

On highways, it is hazardous to stop cars in tunnels. In the event of a tunnel accident, vehicle failure or driver health problems, in addition to sending help, it is critical that arriving vehicles be alerted promptly. Also, abandoning the stalled vehicle in a tunnel, where there is often no emergency lane, to reach the nearest emergency phone can prove very dangerous and should therefore be avoided. In addition, the vehicle fleet without eCall has lower reliability due to age. Therefore, it is precisely the least reliable vehicles not being put in a position to access the PSAP in the event of a breakdown.

European studies and projects are underway to promote the use of after-market eCall through the development of standards, operating procedures, testing and certification (e.g., see [3]), including extending its use to vehicle categories beyond M1 (cars) and N1 (light commercial vehicles) served by the eCall standard. Although eCall devices can retrofit even legacy vehicles, installation requires wiring that the motorist rarely implements without a legal requirement. Especially for older cars, the motorist is not inclined to take on the cost of installation.

Using the smartphone is an apparent complementary solution to eCall for making an emergency call from these legacy vehicles. To ensure the very high level of reliability required of a safety service, monitoring the status of the emergency call service offered by one or more telecommunications operators within the many tunnels along highway networks is necessary. Under this quality-assured condition of coverage, the highway operator can provide emergency call service with the same grade of service as today's landline calls made from emergency phones.

Therefore, the guarantee of continuity of 2G/3G/4G coverage in tunnels requires adopting an appropriate monitoring infrastructure implemented in Italy and SIL 1 certified [4]. We should note that MNOs have no obligation to inform the highway operating company of malfunctions or upgrades, or maintenance of their facilities. For this reason, we introduced the TEZE (Telecommunications Enhanced Zone Emergency-call) system as a quality monitoring system. The first installations have already started in some tunnels of

Italian highways. The TEZE system is not an alternative to eCall (and its evolutions) but offers the same eCall a layer of coverage reliability not yet available today.

To our knowledge, the TEZE system is an early example of a guaranteed quality-monitoring road safety service based on the smartphone (or IVS) and cellular telephony. Unlike multiple driver services based on installing apps and APIs on the smartphone, the TEZE ground infrastructure continuously verifies the cellular radio coverage of at least one mobile operator. Thus, it enables the operator to take timely action to restore its service in case of disruption.

Meanwhile, studies and trials are underway for a system called Next Generation (NG) eCall [5]. The NG eCall standard, started in 2013 and completed in 2017, stipulates that packet-switched IMS emergency calls will have to replace circuit-switched calls. (There is no CS domain in 4G/5G.) NG eCall, which in the communication channel provides much faster MSD data transfer, will also be able to transfer multimedia content, such as video from DashCams and audio messages. The control channel from PSAP to IVS will allow the sending of commands, such as those to sound the horn, make the lights flash, lock or unlock the doors, turn off the vehicle ignition, etc. These will undoubtedly be significant improvements over the eCall service devised around 2000.

The NG eCall specifications, made under the guidance of ETSI, extend the benefits of eCall to all vehicle categories beyond M1 and N1. Directive 2010/40/EU established a framework to support the coordinated and coherent deployment and use of ITS systems in the Union. Then CEN (European Standardization Committee for voluntary standards at the European level) developed a technical specification (CEN TS 17184:2018) to provide eCall services over the PS mobile network using IMS for 4G/5G. The European Commission intends to update the current eCall regulation to include eCall-over-IMS procedures to achieve compliance with PS mobile networks. The new regulation will ensure coexistence between packet-switched NG eCall and circuit-switched eCall. Figure 2 shows how the coexistence could be extended, thanks to the flexibility provided via the ETSI ESInet architecture [5], also including simple and reliable smartphone access, if the proposed TEZE system is included for network monitoring.

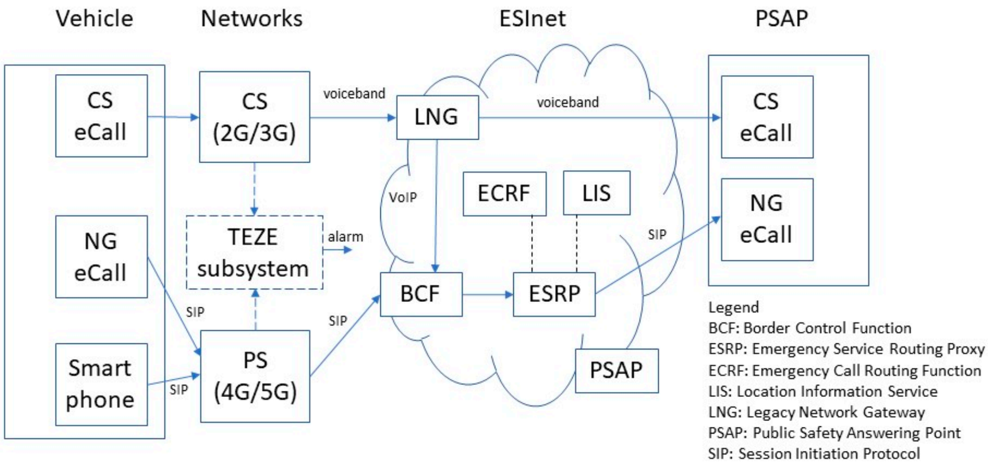


Figure 2. Co-existence of NG eCall and CS eCall.

In NG eCall, the IVS initiates an emergency call via IMS following a traffic accident or at a request from the motorist. The serving mobile network routes the call to a PSAP with a SIP/IP signaling path through an IMS and a separate VoIP path for voice transfer. If the PSAP uses CS and not IP access, a media gateway (MGW) converts VoIP to CS voice. The MSD data stream is sent to the PSAP in the signaling path in a SIP INVITE message that is sent to set up the VoIP call. The voice path is not interrupted or affected by the MSD transfer. Support for 5G is similar, with the gNB replacing the eNB of 4G and the UPF (User Plane Function) replacing the pair of gateways SGW/PGW (Figure 3).

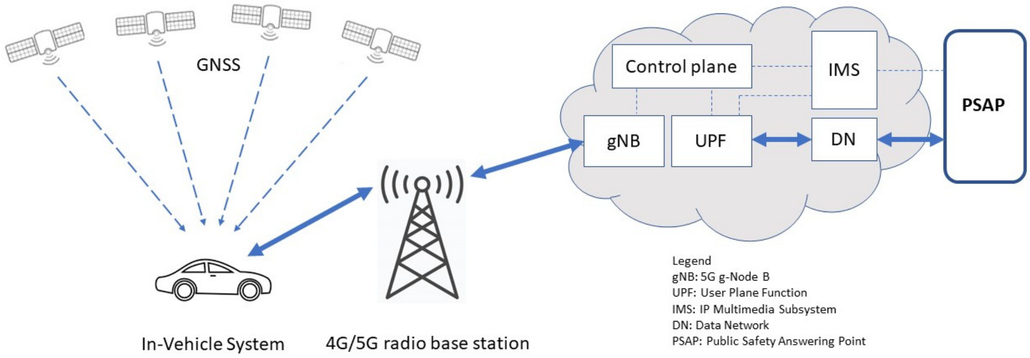


Figure 3. Next Generation eCall system architecture (5G case).

According to uncoordinated national plans, MNOs are expected to phase out 2G/3G and reallocate frequencies to the more spectrally efficient 4G and 5G systems. Therefore, edge IVSs will have to support both CS eCall and PS NG eCall from the beginning, and PSAPs will also have to, in general, support the dual mode and gradually migrate to universal NG eCall service [6]. While subject to some complexities and costs, the migration process poses no technological problems. However, the main Achilles' heel of the system, namely the exclusion of legacy cars, combined with the long commissioning time and easy technological obsolescence, could plague the European emergency call system for a long time. Therefore, in this paper, starting with the example of the TEZE system, we discuss the use of the smartphone as a personal terminal capable of integrating an (NG)-eCall system for all unequipped vehicles.

The remainder of the paper is organized as follows. In Section 2, we examine the uses of the smartphone to improve road safety and provide auxiliary services to motorists. Section 3 introduces the new TEZE system for road safety in tunnels and other critical highway locations, describing the ground infrastructure and main functionalities. Section 4 provides some experimental results in an actual highway tunnel in Italy. In Section 5, we illustrate some possible evolutions of the TEZE system to improve the customer experience and introduce new smartphone-based services in the highway domain. In Section 6, we briefly discuss the low-cost features of the TEZE system and possible, achievable revenues due to integration with the app ecosystem. Finally, Section 7 concludes the paper.

2. Smartphone and Road Safety

Although generally recognized that it can operate as a communication and measurement tool in the Intelligent Transportation Systems (ITS) environment, the smartphone is still largely underutilized nowadays. The smartphone has long since become a personal assistant with the ability to transmit and receive voice, data and video. Equipped with numerous sensors, it enables measurement and monitoring functions of people and their surroundings as an IoT device connected to the Internet. Integrating multiple communication technologies—from 4G/5G to Wi-Fi to Bluetooth—and navigation technologies, such as GPS/Galileo, enables it to be used in a heterogeneous network environment (HetNet). In addition to accessing terrestrial networks, the use of the smartphone shortly will include networks via constellations of LEO (Low Earth Orbit) satellites [7].

European organizations providing emergency services can generally only be reached by voice through public telephony and mobile networks. Meanwhile, different types of text messaging and video and image-sharing applications have also become popular means of communication through social networks, which are very powerful for sharing information. In addition to providing emergency calls, smartphones can transmit much more comprehensive information than the eCall standard.

Conceived in 1999 by Luc Tytgat of the European Union, the eCall standard has its roots in the European Commission's (EC) eSafety initiative of 2002, which recommended the adoption of Intelligent Integrated Safety Systems in vehicles to improve road safety and reduce accidents. Some of the crucial next steps were: (a) the commissioning of ETSI's

Mobile Standards Group (MSG) in 2005 to initiate standardization of the eCall system; (b) the evaluation of a minimum set of data transmission solutions carried out by the GSM, which considered only the in-band modem to be suitable, as at that time, for low bitrate data transmissions, the mobile data channel had disadvantages compared to the 2G voice channel; (c) finally, the EC and ETSI commissioning of 3GPP to standardize an in-band modem specification for the eCall system.

3GPP completed the modem verification, characterization and specification in 2009. Subsequently, 3GPP has repeatedly updated the technical specification of the eCall in-band modem and released numerous releases. Standard EN 16072 [1] provides a detailed description of the operational requirements of eCall. It is complemented by EN 15722, defining eCall's MSD format, and EN 16062, which introduces eCall's HLAP (high-level application requirements) using circuit-switched GSM/UMTS networks.

Such a complex and lengthy standardization process—nearly twenty years from conception to service—conflicts with ensuring timely and effective improvements to road safety in line with technological evolution. The choice to define standardized IVSs with "black box" features that, once introduced to the market, may already be obsolete—if not reprogrammable according to the Continuous Integration, Delivery and Deployment (CI/CD) paradigm—and does not reconcile with ICT evolution. CI/CD ensures the automatic execution of all new features, bug fixes, updates and software upgrades. Even if the CI/CD principle and a "white-box" approach to IVS are adopted, it is still doubtful that the solution adopted will be entirely future-proof.

The current trend in services shows how the market offers a panoply of applications that can be downloaded from the cloud voluntarily and, often, for free. The limitation of the app-based approach is not in the functionality available in the cloud, which is potentially abundant, growing and affordable. The actual limit relies on integrating into a general utility service with guaranteed quality of service, possibly based on ground-based (and in the future possibly via satellite) infrastructure, without placing constraints on either the vehicle manufacturer or the vehicle driver.

While standardized IVSs necessarily have a long lifecycle (ten years or more), in contrast, a user replaces the smartphone on average about every two years. It lends itself, where necessary, to chasing emerging standards on time. The ETSI AML (Advanced Mobile Location) standard for emergency communications, approved in December 2019 (ETSI TS 103 625), provides a suitable example. The AML standard requires all smartphones sold in Europe, as of 17 March 2022, to meet the requirements of EU Delegated Regulation 2019/320 of December 2018. All smartphones sold in the European single market must send location information derived from the caller's device when they initiate an emergency communication. To accurately determine the caller's location, the regulation explicitly requires that smartphones process data from Wi-Fi and GNSS systems that are compatible and interoperable with at least Galileo. The AML protocol transports location data from the smartphone to the PSAP emergency control center via SMS or HTTPS.

3. The TEZE System

The TEZE system (patent pending) defines the architecture of a system for monitoring the emergency call service, manual and automatic, between a vehicle stopped in a tunnel and the telephone operator's service platform. Thanks to the TEZE system, vehicle abandonment can be prevented while ensuring compliance with the highest standard levels of physical safety and IT performance and security.

The TEZE system (Figure 4) consists of the following hardware elements:

- Monitoring probe (e.g., based on Raspberry or similar hardware platform);
- Three modems, each equipped with SIM cards, from different mobile operators;
- IT platform for message management (initializations, alarms, etc.).

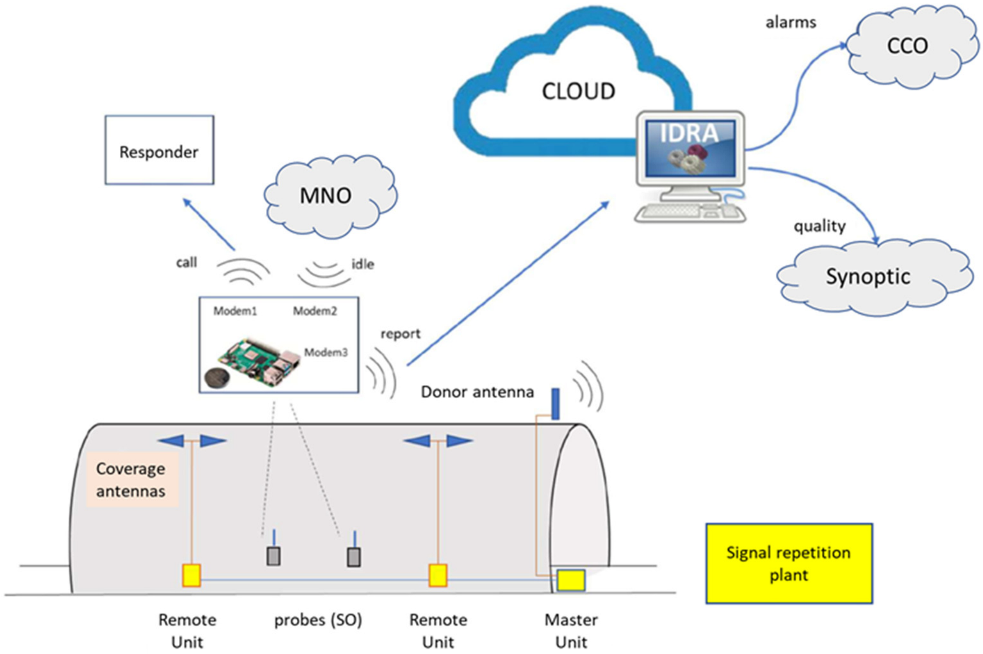


Figure 4. TEZE system conceptual block-diagram in a tunnel installation.

One of the system's essential elements consists of the probe (SO), a cellular radio coverage monitoring and automatic programmable calling device for simulating mobile network user behavior and generating reports on the proper operation of the mobile radio network in the installation area. The probe is intended to monitor the intensity and quality of coverage and to verify success in establishing telephone calls. Therefore, its placement is suitable where it is necessary to check the presence of radiotelephone coverage for security management and emergency response. Some examples of applications are:

- Road tunnels, both in highways and other types of roads;
- Underground parking lots covered by a cellular operator or Distributed Antenna System (DAS);
- Any demarcated area, even outdoors, where it is necessary to be able to contact 112 in the absence of an eCall device or, even if present, it is intended to send a dataset richer than the standard MSD.

Integrating a sequence of closed and open spaces into one single surveillance system proves helpful in a succession of road tunnels, especially in mountainous environments, to create a single "virtual tunnel" to be subjected to integrated surveillance by a single entity.

The probe includes a programmable microprocessor device, e.g., a Raspberry device, a power supply section and buffer battery, and modems, each equipped with a SIM card from one of the telephone operators providing service in the area of system use. The device is designed to operate at maximum operation in a temperature range of −20 °C to +50 °C and has compact dimensions for easy installation.

As illustrated in Figure 4, it is assumed that one or more MNOs possess signal repeater facilities of their cellular system (2G/. . . /5G) within a tunnel tube. The devices associated with these facilities are referred to generically as Remote Units (RUs) in Figure 4 and are assumed to be preexisting.

The TEZE monitoring system is installed within each tunnel tube. It involves the constant-pitch installation of one or more probes within the tube with a maximum separation pitch of typically 400–600 m (the actual distance is determined during installation with a measurement campaign).

The probe includes transceiver equipment (modem) necessary to:

a. perform signal power measurements of the signal received by each RU belonging to the cellular operator's repeater equipment in the tunnel;

b. forward calls to other probes within the same tunnel (in the case of single-tube tunnels) or, in the case of two-tube tunnels, to probes in the other tube;
c. forward calls to automatic responders (RISs);
d. send data to a monitoring system's command and control center (CCO) via a data link established with at least one of the mobile operators in the tunnel.

Calls to the other probes, i.e., to the CCO, are made using the mobile radio signal repeater equipment installed inside the tunnels. The modems inside the probes can forward calls using radio mobile access technologies such as 2G, . . . , and 5G.

The probe records the outcomes of received power measurements and calls forwarded to other probes and communicates these results to the CCO.

As shown in Figure 4, the system may include one or more RISs that the probes can query via calls routed through one or more cellular operators' networks with tunnel-installed facilities.

The probe and, possibly, the RIS send information is acquired inside the tunnel to the CCO via data link for subsequent processing to determine the operational status—active or inactive—of the emergency call service in the tunnel. The CCO, which can be installed in a data center, collects information on the following:

- System self-diagnosis alarms consisting of probes, responders and, where present, the DAS along the tube.
- Features for emergency call verification, including:
    - status (if "IDLE") of operators for 2G, . . . , and 5G;
    - status of the emergency call;
    - system status for each tube.

By processing the received data, the IT platform implementing the CCO can:

- Determine the presence of one or more MNOs within the tunnel and concerning the individual communications technologies used, such as 2G, . . . , and 5G;
- Assess the operational status of the probes ("IDLE" or "CONNECTED") installed within the tunnel tubes; and
- Determine the status ("OPERATIONAL" or "NOT OPERATIONAL") of the emergency call service offered by one or more of the mobile operators inside the tunnel tube;
- Provide diagnostic information on the operational status of the TEZE monitoring system. This information is provided at the individual provider and tunnel tube level.

The TEZE system makes it possible to check whether an emergency call can be made in a tunnel between two probes deployed inside the tunnel and equipped with modems with 2G, . . . , and 5G wireless connectivity technology.

The motorist's smartphone can make the 112 emergency call, provided the following properties are verified:

- User Equipment (UE) enabled for emergency calls (i.e., "not locked");
- UE registered to a cell of the serving operator (in "IDLE" mode, power measurements are received from the radio base station);
- UE with SIM/USIM of a different operator (in which case the UE does not register to the network but makes the emergency call directly through the network of the present MNO);
- UE without SIM/USIM (the UE does not register to the network but directly makes the emergency call through the present operator's network).

The system should monitor the presence of the GNSS signal in the tunnel. The limiting situation is the absence of a signal, which can be caused by factors such as:

- The stable absence of the signal within the tunnel (e.g., due to antenna fault);
- Problems with the Remote Units (RUs) or the repeater equipment;
- Absence of power supply in the tunnel;
- Absence of power at the probe or probe fault.

For the TEZE system, we can divide tunnels into two categories based on the GNSS signal repetition facility within them:

- Tunnels equipped with DAS from the same operator as the TEZE system;
- Tunnels with a proprietary system (third-party cellular operators).

In tunnels served by DAS, the mobile radio coverage is evenly distributed within the tunnel, and appropriate alerts of any system failures or malfunctions can be sent. In tunnels with proprietary coverage (third-party operators), on the other hand, the mobile radio coverage depends on the appropriate systems installed by the different MNOs.

Given the diversity of radio system architectures to be managed, we addressed the issue of the methodology for verifying the coverage status in tunnels separately. In the case of tunnels equipped with DAS systems, we considered one probe per tube suitable because the DAS is equipped with an alarm system. In the case of third-party coverages, the placement of constant-pitch probes (typically every 400–600 m) is expected. Still, taking into account the variable geometry of the tunnels (with or without curvature, having different shapes and sizes, etc.) and the positioning of the MNO radio base stations installed outside, it is necessary to carry out e.m. field quality verification. Therefore, we make field trials dedicated to each tunnel according to a standard procedure.

We validated the procedures and functionalities of the TEZE system against the reference standard ISO/IEC 30141:2018 [8]. A standard is a norm or requirement established for a repeatable technical activity that applies to a common and repeated use of rules, conditions, guidelines or characteristics for products or related processes and production methods and related management systems practices. The TEZE system is a finite-state machine that must ensure full functionality in every operational state without any loopholes. Therefore, strictly following the requirements of ISO/IEC 30141:2018 is a guarantee that critical conditions, which can cause management failures, will not occur in its operation. ISO/IEC 30141:2018 provides a Reference Architecture (RA) for IoT systems defined according to industry best practices.

Using the top-down approach suggested by the standard, we obtained an overall validation of the system [9]. The main characteristics of the TEZE system in terms of performance monitoring concern the following issues: trustworthiness (availability, integrity, resilience, anti-tampering, security, etc.); system architecture (functional and management capability separation, modularity, network connectivity, scalability, etc.); and system functional characteristics (accuracy, flexibility, manageability, real-time capability, etc.). In particular, anticipating the possible implementation of the TEZE system to the very many tunnels of the Italian highway network, integrity, scalability, real-time capability, and anti-tampering/security properties are considered particularly sensitive.

In ISO/IEC 30141:2018, an IoT system is grouped into the following domains. They are the user domain (UD), the physical entity domain, the sensing and controlling domain, the operations and management domain, the resource and interchange domain and the application and service domain. The domain-based reference model applied to the TEZE system is described in Figure 5.

The ISO/IEC 30141:2018 standard defines five types of RAs:

- IoT RA functional view;
- IoT RA system view;
- IoT RA communications view;
- IoT RA information view;
- IoT RA usage view.

The compliance analysis showed substantial adherence and correspondence of the developed system with the ISO/IEC 30141:2018 reference standard in terms of architecture and overall functionality. The list of functional and non-functional requirements provides the set of required attributes, from both operational and organizational, and performance perspectives, highlighting the overall adherence of the developed system to the identified functional and non-functional requirements. Finally, the Requirements Verification Matrix

(RVM) constructed in our study highlights the presence of suitable functionality and attributes in the developed system to meet the previously identified functional and non-functional requirements, providing substantial validation of operation [9].

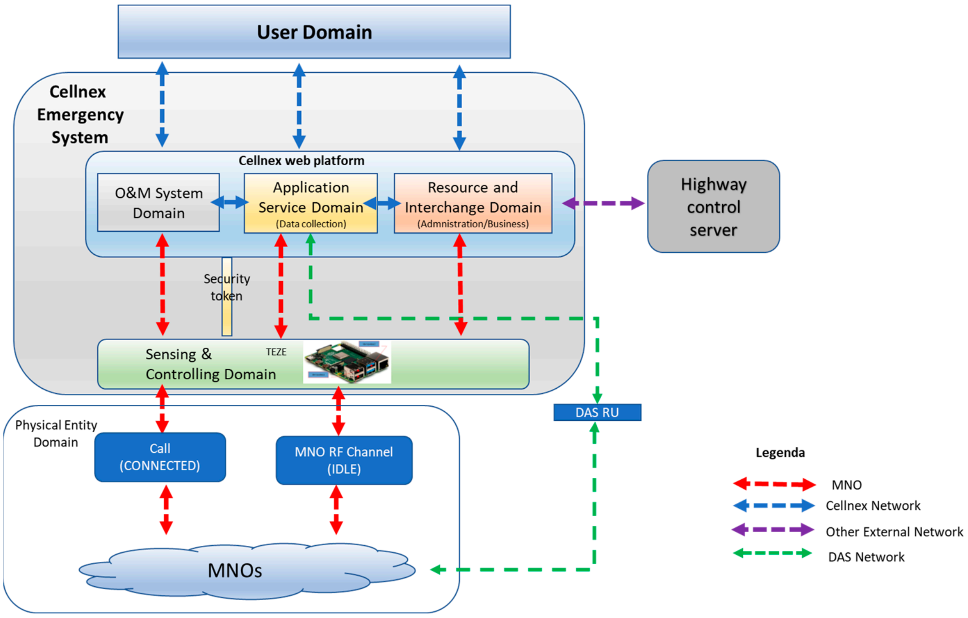
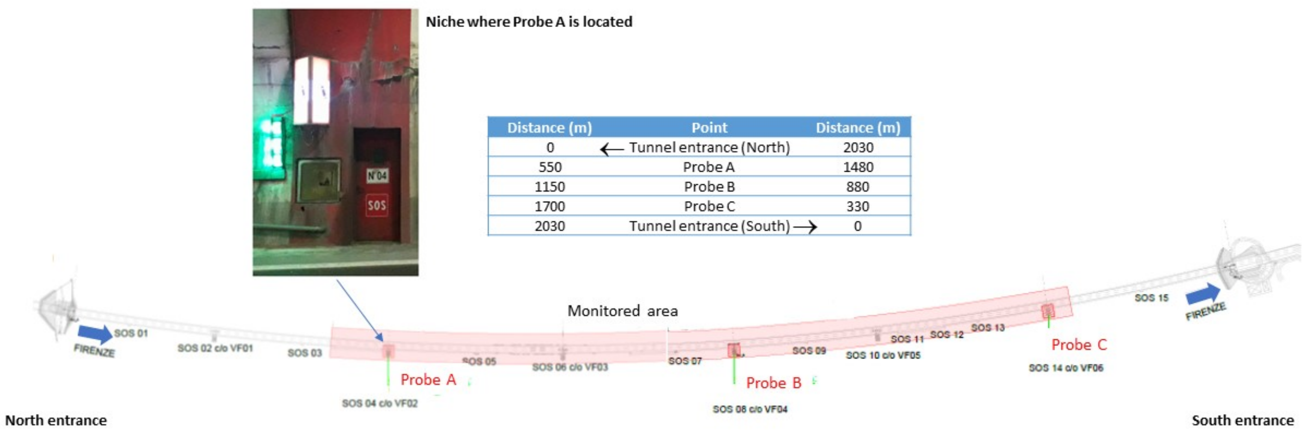


Figure 5. TEZE system domain-based reference model.

4. Setup of the TEZE System and Experimental Results

The TEZE system described in Section 3 has been implemented and tested on the field. This Section refers to three TEZE probes deployed inside a highway tunnel. It is the Manganaccia Tunnel (double tube tunnel, three lanes, 2030 m long) of highway A1 located close to Florence, Italy. Figure 6 reports the tunnel schematic and shows the location of the three probes deployed in the tunnel. The tunnel is serviced by a DAS repeating the signals radiated outdoors by three of the four MNOs providing cellular connectivity in Italy (Op1, Op2 and Op3). We measured the signals at the modems integrated within the TEZE probes installed in the tunnel. In this Section, we provide the received power measurement results.



Distance (m)	Point	Distance (m)
0	← Tunnel entrance (North)	2030
550	Probe A	1480
1150	Probe B	880
1700	Probe C	330
2030	Tunnel entrance (South) →	0

Figure 6. Schematic of the Manganaccia Tunnel close to Florence, Italy.

The TEZE probes periodically measure the power of the control channels of each MNO and for each technology. In particular, they measure the Reference Signal Received Power (RSRP) for 4G-LTE, the Received Signal Code Power (RSCP) for 3G-UMTS and the Received Power Level (PWR) for 2G-GSM. Two MNOs operate 2G, 3G and 4G, while the third one already dismissed 3G in Italy: therefore, the TEZE system in this tunnel avails itself of an 8-times signal redundancy.

As an example, in Figure 7 we report the RSRP measures collected by Probe A, for the three MNOs for about two days. Received power is most of the time about—80 dBm and generally above—100 dBm. The limited number of dips depends on moving vehicles' reflections. However, dips do not occur simultaneously for all the three MNOs so that the correct operations of the TEZE system are not affected. When the measured RSRP is within −90 and −80 dBm, the channel quality is classified as "good" [10].

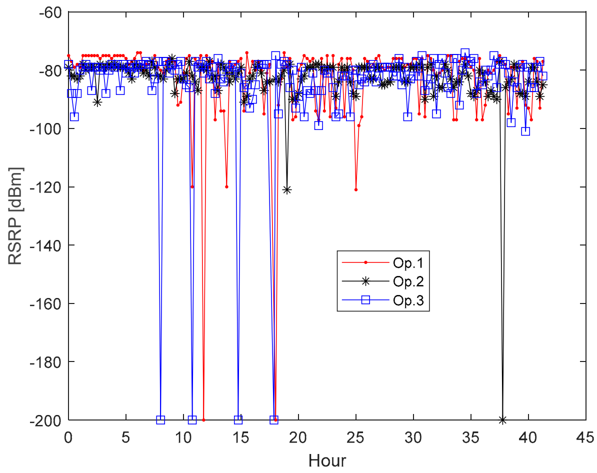


Figure 7. Measured RSRP for 4G-LTE at probe A.

Other radio technologies serve the considered tunnel. As another example, Figure 8 reports the measured signal level (PWR) of the 2G for the three MNOs collected by probe A. As Figure 8 shows, the received PWR is above—80dBm most of the time. Thus, as reported in [11], the channel quality varies between good, very good and excellent. Thus, in the case of a 4G-LTE signal absence, the TEZE system can continue operating appropriately by switching on other radio technologies, such as the 2G-GSM. This mode of operation ensures the TEZE system is highly reliable against malfunctions in the tunnel.

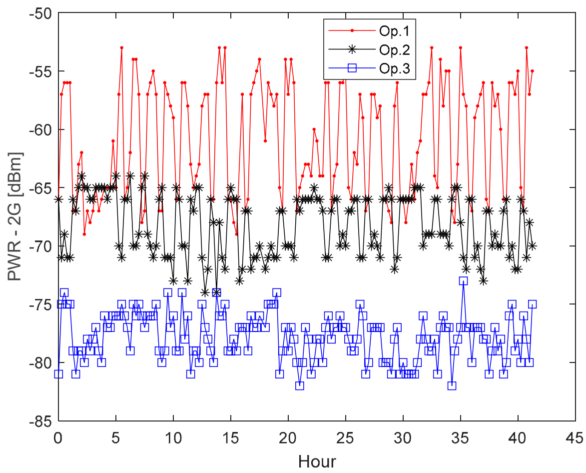


Figure 8. Measured received power (PWR) for 2G-GSM at probe A.

5. Future Perspectives

Most smartphones available on the European market are natively equipped with various communication/navigation media and sensors. Among the former, we have the cellular transceiver (2G to 4G and, in newer models, 5G), Wi-Fi (today Wi-Fi 6), Bluetooth and GNSS (GPS/Galileo) reception. The latter are generally the camera, gyroscope, electronic compass, accelerometer, light sensor and an ultrasound sensor. For specific applications, the audio transceiver can also be employed as an acoustic sensor in addition to long-distance transmission. All sensors quoted above can be helpful in vehicular applications.

Many existing apps based on smartphone sensors can surrogate today's eCall service, although often not connected to the PSAP 112 center (but sometimes to private centers) and with the limitation of being non-guaranteed monitoring solutions, as would be with the TEZE system. On the other hand, based on smartphone sensors, they provide helpful aid in terms of vehicle identification services, accident location and direction of travel. They can also provide additional relevant data (e.g., the number of occupants at the time of the accident). Emergency services can then talk directly to the occupants of the vehicle.

Therefore, in the private market today, acquiring apps for vehicular driving support is easy. An early literature review of apps dates back to 2016 [12]. While there were only a few dozen apps at that time, today, there are hundreds of country-specific apps across Europe, and an exhaustive review of them is virtually impossible. We can, however, provide a classification of the main functionalities offered by distinguishing three cases:

1. Smartphone-only systems (apps operate stand-alone);
2. Systems integrated with the in-vehicle infotainment system (apps integrated with the car's infotainment system);
3. Systems integrated with the car's EOBD (OBD-II in the U.S.), wired or via Bluetooth (apps integrated with the EOBD vehicle status monitoring system).

5.1. Smartphone-Only Systems

It is possible to monitor the vehicle's interior environment with audio/ultrasound tones to automatically capture information, such as the type of vehicle, the number of passengers present and whether airbags are deployed. It is also possible with audio monitoring to predict anomalies in the behavior of mechanical parts of the vehicle before the occurrence of faults.

A traffic accident can be detected using the accelerometer and GNSS receiver and autonomously send the GPS position to the relevant institutions and pre-selected contacts. This mechanism is activated when the force generates g-acceleration above a given threshold.

The accelerometer can also provide information on road conditions, and experiments have been carried out to determine the static conditions of bridges and viaducts.

5.2. Systems Integrated with the Infotainment System

The smartphone can be connected via cable or Bluetooth to the onboard computer and can be operated from the car interface. Generally employed to download music and other entertainment programs from the Internet onto the in-vehicle system, it can also derive geographic maps and integrate information from multiple applications onto one map.

5.3. Systems Integrated with the Car's EOBD (OBD-II)

Intended as a hardware extension of EOBD (European On Board Diagnostic)—in the U.S. OBD-II—of the car connected through the adapter enabling connection to the car's status monitoring system, it can provide value-added services to the user derived on smartphones. For example, in an emergency, it provides help by informing about the status of mechanical components, decodes car engine problems and shows a user's driving behavior with real-time feedback.

It allows users to be alerted if the vehicle has been started without permission, unusual vibrations have been detected, the interface with EOBD (OBD-II) has been disconnected or the vehicle has been moved or towed.

It offers a "virtual mechanic" function that actively monitors the car's electrical system and alerts users if the car's battery voltage is too low and excessive battery consumption is detected. The low battery warning and diagnosis of possible causes are received in case of low battery.

The vast number of features tested by the market for years opens up the possibility of a smartphone-based system to complement (NG)-eCall where present. Building on the quality-of-service monitoring functions already tested by the TEZE system may enable a significant step forward in road safety, particularly on European highways. The ability to update functions via software download can ensure such a system the important future-proof property that virtually assures the absence of obsolescence of the implemented services.

6. System Low-Cost and Potential Revenues

The TEZE system ensures all-time ubiquitous monitoring of the emergency call service in highway tunnels under high safety conditions at low-cost. The low-cost feature is considered a crucial issue for IoT-based services and is being accurately investigated [13]. The TEZE system's low-cost feature is a consequence of the following:

1. Maximum use of existing cellular systems in redundant configuration (multiple operators' coverage with multiple technologies);
2. Implementation of an inexpensive probe's infrastructure based on the IoT principle using COTS hardware;
3. Installation in existing energy-equipped locations;
4. Single platform system management.

We designed the TEZE system to scale to thousands of tunnels; therefore, we envisage its affordability will increase with time. As the system grows, possibly expanding to outdoor highway sections, we envisage an end-user cooperative approach. Our next design step will aim to offer "super-app" [14] services such as those described in Section 5 above. As soon as the number of users increases, attracted by the additional services, crowd-sourcing can also be exploited. Through the super-app and usage of smartphone sensors, it can provide services to the highway company, such as bridge stability monitoring, road surface roughness monitoring, traffic conditions monitoring, and so on. The revenues possibly associated with both end-user services and highway company services will improve the project's sustainability.

7. Conclusions

The EU's eCall system, which has been mandatory since 31 March 2018, has enabled a significant increase in safety on roads and highways, making help and rescue faster and more effective in the event of an accident. Based on circuit-switched 2G/3G communications and an onboard device called IVS, it is not generally available on legacy vehicles and is unlikely to become so. There is a tendency to address some of the limitations of the eCall system with the future NG eCall system based on 4G/5G packet-switched and extended to all types of vehicles on the road. The TEZE system discussed in this paper complements present and future emergency call systems by providing a very high grade of service achievable with a low-cost ground infrastructure for radio coverage surveillance, especially in highway tunnels. A system such as the TEZE system enables the high-reliability use of the 112 emergency service on smartphones. It can immediately ensure the universality of service deployed by the road or highway management company. The use of the smartphone for vehicular emergencies can also pave the way for the provision of new 4G/5G-based services and Wi-Fi in the vehicular environment, as discussed in the paper.

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List of Acronyms

AML	Advanced Mobile Location
CCO	command and control center
CEN	European Standardization Committee for voluntary standards at the European level
CI/CD	Continuous Integration, Delivery and Deployment
COTS	Commercial Off-The-Shelf
CS	Circuit-Switched
DAS	Distributed Antenna System
ETSI	European Telecommunications Standards Institute
GNSS	Global Navigation Satellite System
HLAP	High-level Application Protocols
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IoT	Internet of Things
ITS	Intelligent Transportation System
IVS	In-Vehicle System
LEO	Low Earth Orbit satellites
MGW	Media Gateway
MNO	Mobile Network Operator
MSD	Minimum Set of Data
MSG	Mobile Standards Group
NG eCall	Next Generation emergency Call
OBD	On Board Diagnostic
PS	Packet-Switched
PSAP	Public Safety Answering Point
RIS	automatic responder
RU	Remote Unit
RVM	Requirements Verification Matrix
SIL	Safety Integrity Level
SIP	Session Initiation Protocol
SGW/PGW	Serving Gateway/Packet data-network Gateway (4G)
TEZE	Telecommunications Enhanced Zone Emergency-call
UE	User Equipment
UPF	User Plane Function (5G)
VoIP	Voice over IP

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