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IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received June 5, 2018, accepted July 13, 2018, date of publication July 23, 2018, date of current version August 20, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2858751

From E-911 to NG-911: Overview and Challenges in Ecuador

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This work was supported in part by the *Universidad de las Fuerzas Armadas ESPE* under Grant 2015-PIC-004, in part by PRINCIPIAS, FINALE, and KERMES from the Spanish Government under Grant TEC2013-48439-C4-1-R, Grant TEC2016-75161-C2-1-R, and Grant TEC2016-81900-REDT, and in part by PRICAM from the *Comunidad de Madrid*, Spain, under Grant S2013/ICE-2933.

ABSTRACT For years, emergency attendance institutions in Ecuador worked separately and not all of them had a 24/7 service, resulting in duplicated efforts, a waste of the scarce resources, and an absence of generalized technology. In 2012, Ecuador created an Integrated Security Service, called ECU 911, to address the need of an emergency service articulating all the first response institutions. The ECU 911 relies on the Enhanced 911 technology, having a countrywide presence. Since then, Ecuador has implemented 16 public-safety answering points and 11 decentralized operative rooms, covering all Ecuadorian territory and serving to a population of about 17 million people. The overview presented in this paper demonstrates how the advanced technology supports this new model of emergency attention service based on an Enhanced 911 platform. In addition, the achievements and challenges required to become a Next-Generation 911 service are discussed.

INDEX TERMS Enhanced 911, Next-Generation 911, ECU 911, public-safety answering point.

I. INTRODUCTION

Since the mid-20th century, the first generation of 911 services have been operating in Canada, United States, Mexico, and Asia, while the 112 service has operated in Europe. This first generation of 911 services used the Public Switched Telephone Network (PSTN) to communicate with the Public-Safety Answering Points (PSAP), which dispatched the First Response Institutions (FRIs) such as police, fire brigades, and emergency medical services (EMS) [1]. With the rapid growth of cellular communications, the first generation of 911 services evolved to Enhanced 911 (E-911) [2], incorporating and supporting calls from mobile devices. In 1999, the US government enacted the Wireless Communications and Public Safety Act, which made mandatory the use of 911 as a universal emergency number, and the E-911 was defined as the base technology for handling calls made from mobile cellphones [3]. In the last 10 years, Information Communication Technologies (ICT) have significantly evolved with the proliferation of the Internet, mobile data services, short message services (SMS), smartphones, social media messaging services like Twitter or Facebook, and Voice over IP (VoIP). This evolution of the ICT highlighted the need of rethinking and redesigning the 911 service in order to accommodate a wide range of data formats, technologies, and media in a Next-Generation 911 (NG-911) system [4], [5]. This wide range of communication technologies created new challenges in the integration of hardware, software, procedures, policies, standards, facilities, knowledge, and training, and it aims to enable a coordinated and effective emergency response from the FRIs [5]. Nevertheless, these new NG-911 components create new opportunities for information sharing, multi-media communication, improved services, and data back-up for future use as evidence at courts.

Thus, after recognizing the need of having a centralized 911 service in Ecuador, the government commissioned a team to design and implement a nationwide emergency service. This work explains the implementation of the Ecuadorian Integrated Security Service, called ECU 911, so that other countries and jurisdictions can take advantage of Ecuador's experience and insights. The ECU 911 architecture, service, implementation, management model, and results, are discussed along the document. The ECU 911 model is a working E-911 based service and has many elements which made it a viable alternative to migrate to an NG-911 architecture. Hence, it can be a reference, especially for countries with limited resources and a wide variety of covered regions. In addition, the achievements and challenges required to become an NG-911 service are discussed, allowing us to emphasize the main points to take into account when an actual E-911 service is migrated to NG-911. Some technical details are included in several sections which could be basic concepts for the expert, but they are expected to help the general reader to better understand the technology and its related challenges in this setting.

This manuscript is organized as follows. Section II explains the motivation behind the ECU 911. Section III discusses the management model and how ICT are integrated into the ECU 911. Section IV provides a summary of the achievements of the service in the last five years and the challenges to migrate to an NG-911 based service. Conclusions and recommendations for future implementations are provided in Section V.

II. MOTIVATION FOR ECU 911

Ecuador is a developing country located on the Pacific coast of South America, where a population of approximately 16.7 million people is spread over 256,370 km^2 [6]. For many years, the FRIs (*e.g.*, police, fire brigades, and public or private health services) worked separately, and each institution had a different phone number, which also varied from region to region. Not all the institutions were available 24/7, and only the police owned a voice trunking network covering most of the country regions. In general, the response effort from the FRIs was redundant, which strained the available resources and increased the cost by deploying more resources than necessary. In the case of disasters or large scale emergencies, there were multiple calls to each institution requesting for help, which increased the time to respond and was difficult to coordinate. Land-line and cellular-phone calls were the only way to request for help in case of an emergency, and new technologies were not integrated. Although each institution made a significant effort to provide with the best service to the community, the lack of coordination and a unified command was preventing FRIs from performing their duties effectively.

These problems prompted the Ecuadorian Government to form a multidisciplinary team in order to research how to use ICTs and develop management models for an E-911 service in Ecuador, which led to the ECU 911 proposal. This team visited relevant PSAPs in North America, Europe, and Asia, in order to design and determine the best possible solution for Ecuador. During these visits, the team collected relevant information about procedures, technologies, and successful cases from the analysis of PSAPs. These cases were carefully investigated according to the Ecuadorian realities, such as socio-economical conditions, the geographic organization of the country, already existing institutions, use of new technologies, penetration of mobile phones and the Internet, use of social networks, and statistics of accidents and emergencies [7], [8].

The team amalgamated these considerations and proposed a unique management model, which is illustrated in Fig. 1 and explained in Section III.

III. ECU 911 MANAGEMENT MODEL

The management model of ECU 911 includes the components illustrated in Fig. 1 and labeled as follows: ① alert mechanisms; ② characteristics of the PSAPs; ③ emergency coordination; ④ data treatment; and ⑤ data services to third parties. Within this model, several FRIs are considered and coordinated by the ECU 911, namely, Police, EMS, Fire Brigades, National Agency of Traffic, Social Security, Red Cross, Armed Forces, Risk Management Secretary, and some Municipal Enterprises [9].

It is relevant to highlight that the Integrated Security Service has the hierarchical organization depicted in Figure 2. Basically, it consists of a General Direction, three Technical Subdirections, seven National Directions, and seven Zonal Technical Subdirections (one for each regional PSAP). This organizational structure allows the administration of all the services to collaborate in a coordinated way, including about 3,000 people countrywide and seven collaborating institutions. The General Direction is responsible for managing the service and its timely response to emergencies and alerts. The Technical Subdirection of Doctrine has two main functions: *(i)* to train all the staff members regarding with emergency response; and *(ii)* to elaborate all the regulation and procedures to attend alerts and emergencies, and to transfer them to the FRIs. These tasks are executed by the Academics in Emergencies National Direction and by the Regulators in Emergency National Direction, respectively.

In addition, the Technical Subdirection of Technology is responsible for all the technological platform used in the PSAPs. This last has two subordinated areas. The first one is the Project and Innovation National Direction, which is responsible for developing new projects, boosting research, and implementing those applications that are needed for an adequate service operation. The second area is the Technological Infrastructure Management National Direction, which ensures the proper functioning of all the technological infrastructure deployed to receive alerts and video surveillance, to communicate and coordinate emergency responses. The Technical Subdirection of Operations has three main functions: *(i)* inter-institutional relations, which means the coordination with all the FRIs that are working together under the centralized coordination of the ECU 911; *(ii)* control and coordination of all the operative processes in each PSAP and countrywide; and *(iii)* unifying all data, preparing reports, identifying trends, and preparing summaries aimed at a better planning of the effective and efficient response to emergencies, according with local and international regulations.

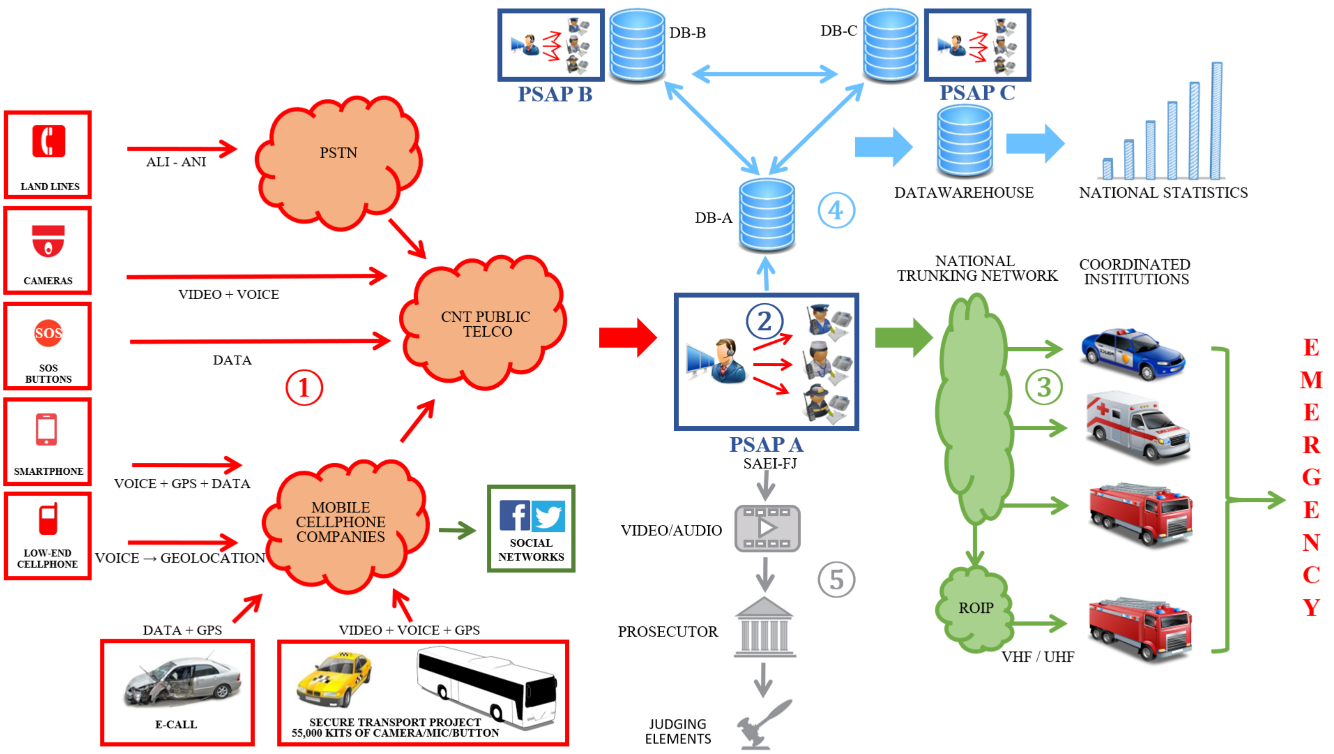


FIGURE 1. ECU 911 management model, as currently running. The five main components are: ① alert mechanisms; ② PSAP characteristics; ③ emergency coordination; ④ data treatment; and ⑤ services to third parties. See text for detailed explanation.

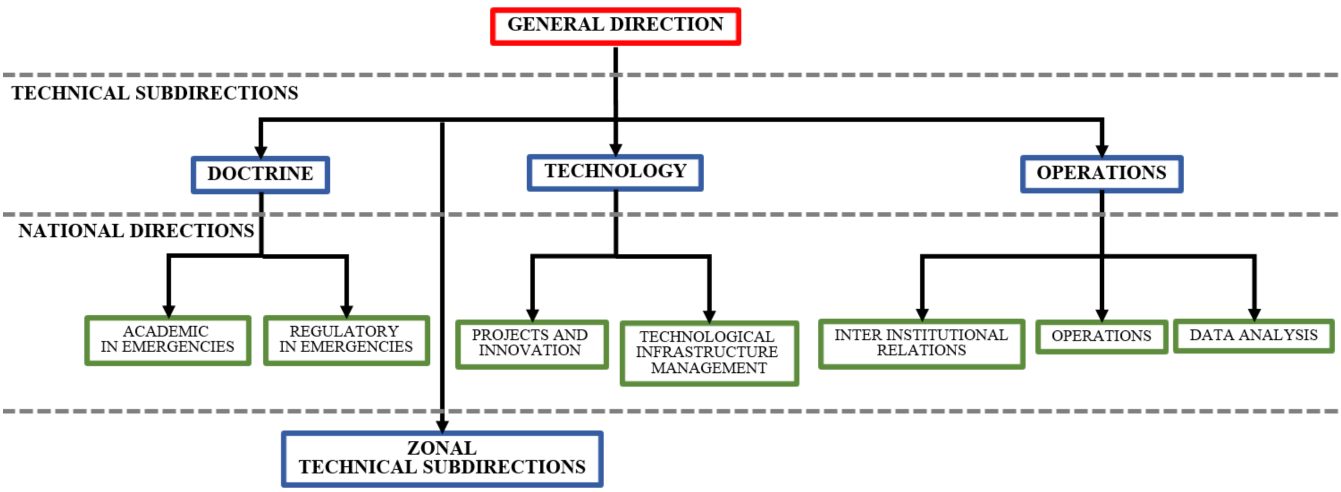


FIGURE 2. Organizer of the Integrated Security Service ECU 911. There is one General Direction, three Technical Subdirections, seven National Directions, and seven Zonal Technical Subdirections (one per each Zonal PSAP countrywide).

These functions are executed by the Inter-Institutional Relation, Operation, and Data Analysis National Directions, respectively. Finally, there are seven Zonal Technical Subdirections which manage the operation of the Zonal PSAP and their subordinated Local PSAP or Decentralized Operative Rooms (DOR), as explained in Table 1 and seen in Fig. 3.

The following subsections offer an overview on the specifics of the alert mechanisms, the characteristics of the PSAPs, the emergency coordination process, and data treatment and available services.

A. ALERT MECHANISMS

Alert mechanisms refer to all the available methods used to alert to the nearest PSAP in an emergency event. Based on ICT availability, penetration, and applicability, alerts can be made by video cameras, SOS buttons,

TABLE 1. Hierarchical distribution of the 7 Zonal PSAP, 9 Local PSAP and 11 DOR of the Integrated Security Service ECU 911 in Ecuador.

Zonal PSAP	Local PSAP	DOR
Quito	—	Rumiñahui/Mejía/Orellana
Samborondón	Babahoyo/S. Cristóbal	Quevedo/S. Elena/Bolívar
Azuay	Macas	Cañar
El Oro	Loja	Zamora Chinchipe
Ambato	Riobamba	Cotopaxi/Pastaza
Portoviejo	Sto. Domingo	Manta
Ibarra	Esmeraldas/Tulcán/N. Loja	—

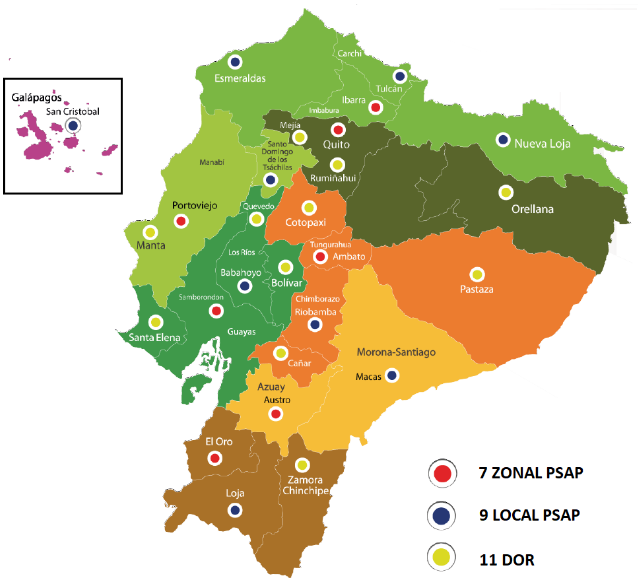


FIGURE 3. PSAP location in the continental and insular regions of the country, showing that there are 7 zonal centers, 9 local centers, and 11 decentralized operative rooms [10].

phone calls, and many other tools. Different telecommunication companies are connected with the ECU 911 centers over the country. This telecommunication companies concentrate and route incoming alerts to the nearest geographic PSAP located in the user region, in order to ensure a fast response by dispatching the nearest available resources.

Alerts contain information related to events, and they are evaluated to check if they are actually an emergency or not in terms of established procedures defined by the Technical Subdirection of Doctrine and the Regulatory in Emergencies National Direction. The main alert mechanisms in the ECU 911 are described next, and all of them are labeled as ① in Fig. 1.

1) LAND LINES

This mechanism includes the calls made through the PSTN from fixed land-line phones. The information regarding the emergency event is collected with the Automatic Location Identification (ALI) or Automatic Number Identification (ANI) provided by the telephone company. This information permits the geolocation of the caller's address as additional information while processing the emergency.

TABLE 2. Technical characteristics of the UIT-T G.655.D optical fiber used to connect the video surveillance cameras.

Attribute	Detail	Value
Mode field diameter	Wavelength	1550 nm
Chromatic dispersion	λ_{min}	0.0396 (λ - 1550)+2.80
	λ_{max}	0.0674 (λ - 1550)+6.20
Attenuation coefficient	max. at 1550 nm	0.35 dB/Km

2) CAMERAS

There are 4,145 cameras installed in public spaces in different cities around the country [11]. These cameras usually require a transmission rate of 3 Mbps for standard video quality and 5 Mbps for high definition video quality. These public space cameras are complemented with additional cameras, such as vehicle license-plate readers. Each of these peripheral devices is connected to the PSAP through an Optical Fiber (OF) network, by using cables of type ITU-T G.655.D [12]. The technical characteristics of this OF are described in Table 2. It is well known that total attenuation A of a given link is given by

$$A = \alpha L + \alpha_s x + \alpha_c y \tag{1}$$

where α is the attenuation coefficient, L is the link length, α_s is the mean splice loss, x represents the number of splices in a link, α_c is the mean loss of line connectors, and y is used for number of line connectors in a link (if provided). The chromatic dispersion of the link (D_{Link}), given in ps/nm, is calculated by using

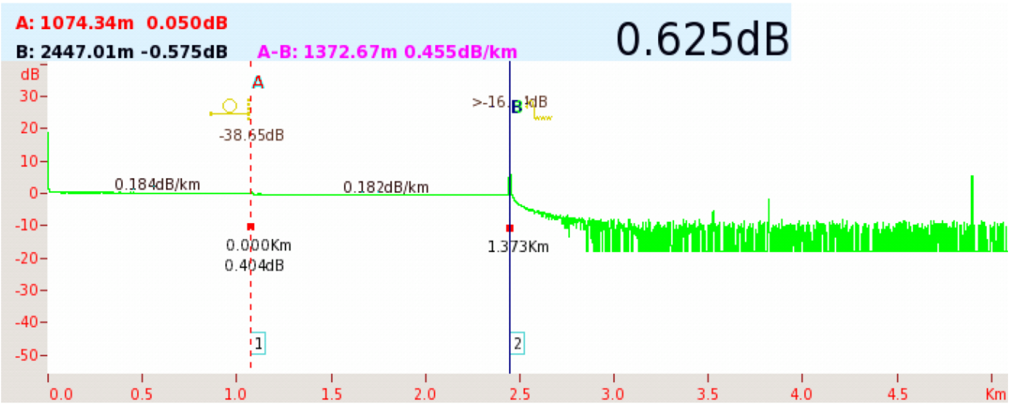
$$D_{Link}(\lambda) = L_{Link}[D_{1550} + S_{1550}(\lambda - 1550)] \tag{2}$$

where D_{1550} is the chromatic dispersion at 1550 nm and S_{1550} represents the chromatic dispersion slope. The theoretical value of A was compared with real Optical Time-Domain Reflectometer (OTDR) measurements of the installed cameras, as shown in Fig. 4 for one example in a specific link.

For some special events, wireless portable cameras are installed and connected to the PSAPs via a Long Term Evolution (LTE) network, which allows rapid field deployment [13]. The cameras in the LTE network usually operate at 1 Mbps [14]. Due to the presence of four active volcanoes in Ecuador, early-alert thermal cameras are installed in high-risk zones near to Cotopaxi and Tungurahua volcanoes, which are the most concerning ones [15], [16]. One of these cameras is specialized in providing temperature information in the form of a pixel image. This camera is installed in a Cell On Wheel (COW) solution, and it provides information about the Cotopaxi crater temperature, which is directly fed to the Ecuadorian National and Polytechnic Geographical Institute (IGEPN) so that volcanologists can receive and study such information on real time.

3) SOS BUTTONS

Up to 500 SOS buttons are installed in public locations to communicate directly with the PSAPs. In the case of an emergency, the ECU 911 video operator can access the Closed



Nm Evts: 2 ORL enlace: 36.69 dB

Evento	Distanc. Km	Pérdida dB	Reflect. dB	Pend. dB/km	Sección Km	Pérd. T dB
1	0.000	0.404	-38.65	0.184	1.074	
2	1.373		>-16.74	0.182	1.373	0.250

FIGURE 4. Practical example of OTDR test of the installed OF, where it is possible to observe the total attenuation *A* of 0.625 dB for this 1.373-km link.

Circuit Television (CCTV) videos to identify the type of emergency and to guide then the FRIs to those locations. These buttons employ 3G technology to communicate via Short Message Service (SMS) to an individual server located at each PSAP. The followed sequence starts when the button is pressed, and then the system communicates the alert via SMS to an address. Afterward, the carrier Access Point Name (APN) receives the connection and message and it routes the content towards the corresponding PSAP location, by considering the geographical location where the button is installed. A similar solution deployed for the e-call infrastructure is also being applied nowadays. This solution consists of transmitting complete TCP/IP packages, which ensures a higher probability of alert arrival since an ACK is received with TCP protocol. In this second scenario, the button connects directly with a web-service deployed in a redundant server infrastructure in the PSAP located in Quito. Once the alert is communicated, the server dispatches the alert to the respective PSAP.

4) SMARTPHONES

Current smartphone devices can transmit information like Global Positioning System (GPS) coordinates in addition to voice calls. When it is necessary to determine the device location during the emergency, it can be captured in the PSAP thanks to a terminal installed by each operator. It also can be mentioned that there exists an application, so-called *ECU 911 Smartphone App*, which can be downloaded from AppStore or PlayStore and installed on any smartphone using iOS or Android operative systems. With this application, the user previously enters basic personal information, and in the case of an emergency, this information is sent to the nearest PSAP along with the approximate geographic coordinates, which makes possible to dispatch a resource to the location. Up to 57.6% of Ecuador population owns smartphones with mobile broadband service [17], and more than 100,000 users have downloaded this mobile application. Its installation is strongly advised to tourists who are visiting Ecuador, and it is useful for international roaming customers since their locations cannot be obtained automatically from their calls to the ECU 911 because of the so-called phone-number masking process [18].

5) LOW-END CELLPHONES

A large number of Ecuadorian people still owns low-end cellphones, constituting 37.2% of the cellular devices, and which usually do not have GPS data, Wi-Fi interface, or data transmission options, but rather they only have voice calls and SMS as communication alternatives [17]. In this case, the cellphone company must provide the approximate location of the caller by using the Base Stations (BS) density method. This location is obtained by comparing the Received Power (P_R) and the Time of Arrival (ToA) of the cellphone in at least three BS. These characteristics of radioelectric propagation change proportionally to their distance (d), so that when the cellphone moves away from a given BS, then P_R decreases according to the well-known ideal free-space equation [19], expressed as

$$P_R = P_T \frac{G_T G_R}{kd^2}; \tag{3}$$

where P_T is the power transmitted by the cellphone; G_T and G_R are the transmitter and receiver antenna gains, respectively; and $k = (4\pi)^2/\lambda^2$ is a constant when fixed the wavelength (λ) of the used frequency. For a more realistic approximation, it is necessary to consider additional factors like spatial variations of the used antennas (θ, ϕ), their polarization depending on spatial variables (α, β), and fast or slow fading caused by reflections as external factors. We can express their relationship as follows,

$$P_R = P_T \frac{G_T(\theta, \phi) G_R(\theta, \phi)}{k d^\alpha L_S L_F} P_M(\alpha, \beta) \quad (4)$$

where P_M is the polarization mismatch, L_S is the shadow fading, and L_F is the fast fading. In order to find the *ToA* [20], we assume that (x, y) are the position coordinates of the cellphone, and that (x_i, y_i) are the coordinates of the i^{th} BS, for $i = 1, 2, \ldots, M$, and where M is the total numbers of receiving BSs. Distance d_i between the mobile cellphone and the i^{th} BS is given by

$$d_i = \sqrt{(x - x_i)^2 (y - y_i)^2}, \quad i = 1, 2, \ldots, M \quad (5)$$

and then the *ToA* is calculated as $t_i = \frac{d_i}{c}$, with c denoting the speed of light. If disturbances are grouped in n_i, then r_i has to be instead considered, which is given by $r_i = d_i + n_i$. An additional parameter to be considered is the BS density, which is given by between-BS distance (D_{BS}). Hence, with these three parameters (P_R, *ToA*, and D_{BS}), the location of a cellphone can be calculated according to the specifications shown in Table 3. Note that this location procedure is applicable to smartphones with their GPS option disabled.

TABLE 3. Specifications for cellphone location based on BS density.

BS density	Distance between BS	Location's accuracy
Very High	$D \leq 500m$	$\leq 50m$
High	$500m < D \leq 1000m$	$\leq 100m$
Medium	$1000m < D \leq 3000m$	$\leq 200m$
Low	$D > 3000m$	$\leq 500m$

The Ecuadorian Telecommunication Control and Regulator Agency mandated to service providers the installation of hardware and software in order to be able to identify the call locations from low-end cellphones. Before this mandate, low-end cellphone location was extremely difficult to do, and E-911 service reliability was strongly jeopardized. Developing countries like Ecuador must definitively consider how to obtain the locational information of the users with low-end cellphones, because the permeation of smartphones may still take a long time in them due to socio-economical conditions.

6) E-CALLS

E-calls are also referred to as Advanced Automatic Collision Notifications. This system is automatically activated when the in-vehicle sensors receive signals of a serious accident or crash [21]. At that moment, a telecommunications transceiver sends the accident alert information to the nearest PSAP, and this information can include the time of the accident, the location of the crashed vehicle, reference points, or the last-known travel direction. It is possible to activate this alarm by pushing a button in the car, and this option is also valid when somebody is witnessing the accident. In rural roads, this function has been proven to be extremely useful [22]. According to the European Telecommunications Standards Institute (ETSI) [23], an E-call carries, by means of mobile wireless communications networks, a standardized minimum data set and establishes an audio channel between the vehicle occupants and the contacted PSAP. The Emergency Service Category value is the 8-bit frame used for mobile-originated emergency calls to indicate the particular type of emergency presented, as is shown in Table 4. Specific flags or discriminators are additionally included, allowing to distinguish between emergency calls made from mobile terminals and E-calls made from in-vehicle terminals, as well as to distinguish between manually and automatically triggered E-calls.

TABLE 4. ETSI Emergency Service Category 8-bit message information description. This service provides the network with information about several services invoked by the user equipment.

Bit	Information	Discriminator
1	Emergency call	Mobile terminal
2	Police	- -
3	Ambulance	- -
4	Marine Guard	- -
5	Mounntain Rescue	- -
6	E-call	Automatically initiated
7	E-call	Manually initiated
8	Is spare and set to "0"	- -

7) SECURE TRANSPORT PROJECT

The National Transit Agency (ANT in Spanish) aims to control transit and transportation issues, and hence, it has been included in the ECU 911 as a Secure Transport Project (STP) entity. The STP consists of cameras, microphones, and emergency help buttons that are installed in more than 55,000 buses and taxis over the country. Audio and video streams from microphones and cameras are recorded in real-time on ANT servers. When there is an alert in the vehicle or when the help button is pressed, the voice, video stream, and GPS coordinates are redirected to the nearest PSAP, where evaluators can assess the emergency with video and audio feedback from the car in real-time, and then they can accordingly coordinate the FRIs response. The connections to the taxis and buses are made through a 3.5G network [24] using High-Speed Packet Access (HSPA+), which is a fusion of mobile protocols High-Speed Downlink Packet Access and High Speed-Uplink Packet Access. Also, the Wideband Code Division Multiple Access (WCDMA) protocol is used to carry data at high speeds, allowing mobile operators to deliver high-bandwidth applications while including video streaming and data originated from public transport units. The general characteristics of the components considered for this project are listed in Table 5.

8) SOCIAL NETWORKS

Social networks are becoming a useful way to communicate and interact with the ECU 911. However, all the information displayed in social networks regarding to the Integrated Security Service ECU 911 is only informative, and users willing to report any emergency are encouraged to make it through

TABLE 5. Elements and technical characteristics of the on-board equipment for secure transport project.

Cameras	Video compression	H.264 / MJPEG
	Video Bit Rate	32Kbps - 16Mbps
	Encoding level	H.264
	Max. Resolution	1920 × 1080
	Standard	ONVIF, PSIA, CGI, ISAPI
	Power Supply	12 VDC / PoE
	Frame Rate	30fps (1280 × 720)
Movile DVR	Audio compression	OggVorbis, 16Kbps
	Recording resolution	4CIF/DCIF/2CIF/CIF/QCIF
	Video bit rate	Max 8 Mbps
	Hard disk driver	Support up to 2TB capacity
	Alarm output	2 channels
	GPS	Antenna SMA interface
Microphone	Frequency	20Hz-20kHz
	S/N ratio	60dB
Router	LTE/4G Wi-Fi	FDD-LTE/TD-LTE/WCDMA/ EDGE/GPRS/GSM
	Band	Tri-Band WCDMA: band 1/5/8
	Bandwidth	HSPA+: downlink 42 Mbps uplink 5.76 Mbps
	Transmission Power	< 23dBm
	Receiving sensitivity	< 104dBm

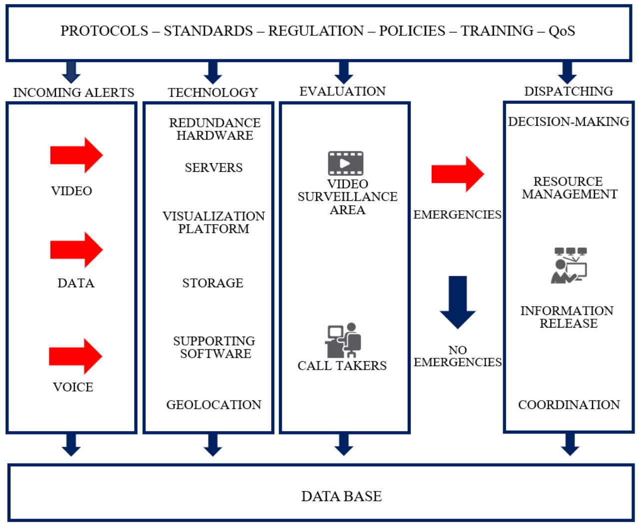


FIGURE 5. ECU 911 PSAP organization model diagram.

one of the available standard channels to contact with the nearest PSAP, or to use the ECU 911 mobile application [18]. In fact, social networks are monitored and followed by a special group of staffers who handle messages in two ways, namely, they encourage the caller to get in touch with the ECU 911 to receive help, and they simultaneously contact with the respective PSAP about the emergency. The strength of social networks lies in the ability to communicate messages related to safety, traffic and road condition, and natural disasters, to a very large community. Another important use of social media is to advertise and to promote the ECU 911 services, as well as to educate the public about the appropriate use of its services.

B. PSAP CHARACTERISTICS IN ECU 911

Since 2012, ECU 911 has built 7 zonal PSAPs, 9 local PSAPs, and 11 DORs. Locations and distribution of these PSAPs and DORs are illustrated in Fig. 3 over a map of Ecuador and Galapagos Islands. The characteristics of PSAPs in the ECU 911 are labeled as ② in Fig. 1.

PSAPs and DORs are designed to host necessary infrastructures, such as facilities, personnel, and the technology required to handle the coordination of emergencies. From these locations, FRI resources are dispatched and coordinated during the emergency. Fig. 5 shows the PSAP organizational model diagram and the elements included in the emergency attention process. The PSAP organization model explains the way alerts are received, processed, transferred, and attended by the participating institutions in a territory, and it also outlines how the feedback is assembled in order to improve all these processes. All of these actions are made using technological platforms, which can receive different information formats and standards according to the Ecuadorian population needs. For instance, the ECU 911 platform receives more alerts originated in cellphones or land-lines (91.5% combined) than those alerts received by video surveillance (5.0%) or other mechanisms (3.5%), as shows us Table 6. This distribution corresponds with the number of mobile cellphones and land-lines available to the population [17].

TABLE 6. Emergencies attended, according to the alert mechanism used to report them to the PSAP.

Ord	Alert Mechanism	Percentage
1	Cellphones	65.1%
2	Land-lines	26.4%
3	Video surveillance	5.0%
4	Other	3.5%
	TOTAL	100 %

In the first instance, there is an interface which receives information through audio and/or video recordings, as well as the data from incoming alerts. Redundant equipments are provided to ensure continuous service, such as servers, visualization hardware, specific supporting software, storage equipment, or geolocation applications. From here, information is routed to dispatchers or surveillance consoles to be assessed and used in the alert attention process.

In the video surveillance area, there are video analyzers who observe the cameras located in their sector of responsibility. When analysts detect an abnormal situation, they immediately alert the institutions and start an emergency process. At the same time, all the information is saved on video surveillance servers to be backed up for future use.

Call takers are the first contact person for incoming calls. These operators evaluate alerts and they determine whether there is actually an emergency or not. In this evaluation process, as shown in Fig. 6, they combine information obtained from other PSAPs, FRIs, video surveillance areas, training, experience, and existing regulations by using the ECU 911 platform. All of the aforementioned actions are made over the ECU 911 technological platform, and the

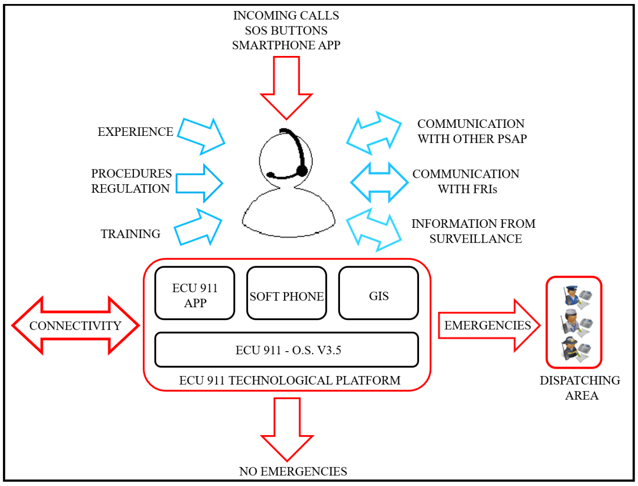


FIGURE 6. Schematic of the alert evaluation process. Call takers obtain information from other PSAPs, FRIs, or video surveillance, and they combine them with their experience, regulations, procedures, and training, in order to evaluate the incoming alert.

objective of this platform is to provide the operator with the necessary information to decrease the evaluation time before transferring the emergency to the FRIs.

At the dispatching area, members of each institution allocate resources within a geographical region. Resource dispatchers collect all the information regarding the emergency and decide which resources are needed to handle the emergency and whether it is necessary to coordinate with other PSAPs, or with other institutions. The leading institution will coordinate with other institutions regarding the emergency response after the dispatch. The institution which leads an event is the one that has the most relevance in the emergency attention. For instance, if it is a fire in a building, fire brigades will lead the emergency, but not police or health, even if their units were moved too.

All the data, videos, transferred calls, and communications, are saved for backup as well as for the analytical process of the operation after the response. This is done in order to assess the response quality by measuring the response time of each instance, and it also allows us to obtain statistical reports and to feedback the first response crew about possible improvements in their services, as well as to assess the response quality with the international standards.

The ECU 911 has its own protocols, standards, regulations, policies, training processes, and Quality of Service (QoS) requirements, and all of these elements defined by the Technical Sub Direction of Doctrine govern the actions of each of the members. Additionally, Ecuadorian law has provisions for criminal charges for the leaking of information related to emergencies.

C. EMERGENCY COORDINATION

When an emergency has been identified and transferred to its corresponding FRI, the dispatch operator communicates the emergency to units over the National Trunking Network (NTN), which covers about 95% of the populated areas in the Ecuadorian mainland territory as well as the Galapagos Islands, with 75 repetition sites and about 25,000 radio transceivers. NTN works with APCO-25, which is a suite of standards for digital radio communications for federal public safety organizations [25]. The NTN and its infrastructure are managed by the National Communication Corporation as a public telecommunication enterprise in Ecuador.

Dispatch operators must communicate with the FRIs resources in the territory, and they must provide information such as the type of emergency, priority, or location, and all the available data for a fast and effective response. They also follow the progress of the emergency in accordance with the procedure laid out by ECU 911 and by the institutions.

In some cases, fire brigades of rural municipalities do not have NTN coverage and they use their own VHF/UHF radio systems, which are connected to respective PSAPs by Radio over IP (RoIP) nodes [26]. This connection permits a communication link between fire brigades with ECU 911 PSAPs, and when necessary, with third-party institutions in order to coordinate their participation. The emergency coordination is labeled as ③ in Fig. 1.

If an emergency requires the involvement of EMS and victims need to be hospitalized, then the health console operator coordinates the bed availability and the needed specialists with the hospitals nearby, while the ambulance is carrying the victim. Likewise, social security and/or private health insurance coverage are coordinated to ensure the required service and care. This service is advantageous in cases where there are multiple victims who need to be moved to more than one hospital, and it also helps to prioritize injuries.

Whenever a PSAP is out of operation due to severe physical or technological damage to its infrastructure, there are procedures and protocols to re-route the calls from this PSAP region to other PSAPs. This re-routing is done hierarchically among PSAPs to support the emergency calls of the affected area. The PSAPs load must continuously be reviewed in order to prevent service interruption when power outages, big emergencies, or natural disasters occur.

D. DATA SERVICES AND THIRD PARTIES

All the information regarding video surveillance, calls, alerts, attended emergencies, and dispatched resources by the ECU 911, is stored on a local Data Base (DB) at each PSAP facility. In this process, the first instance is written to a temporary server. If video and call records are not used for any process, they are deleted after a given time period. If the information is required for any purpose, then it is permanently saved on another permanent-storage server to be used in the future. According to the existing laws, the data on the permanent storage must be preserved for years.

DBs of the PSAPs are interconnected via an optical fiber network, which allows them to share the stored information in a Centralized Data Warehouse (DWH) managed by the ECU 911 Data Analysis National Direction. By using the DWH, ECU 911 can analyze the reports about global or specific emergencies in the country. It can also share information with

FRIs for backup, and it can review the information in order to improve operations [27]. The statistical information is shared with other ministries for security purposes, and it follows all the necessary information privacy policies, procedures, and laws. Each of these is illustrated as Data Treatment section in Fig. 1 labeled as ④.

ECU 911 also considers media to allow data services to third parties. The Automatic Information Delivery Service–Prosecution Function (SAEI-FJ in Spanish) is a critical information sharing application implemented by the ECU 911. It permits the collected and stored video and audio files to be used as evidence in courts for legal cases [28]. There are SAEI-FJ servers in each PSAP, and those servers can be accessed upon requests by Justice Officials. This procedure ensures the confidentiality of the materials while preventing the information manipulation. The data service for third parties is marked as ⑤ in Fig. 1. This service is an initiative to share ECU 911 data with other public institutions, but only Justice cooperation is implemented at this moment.

IV. FROM E-911 TO NG-911

As the technology continues to evolve, VoIP applications become most popular, social networks continue winning adepts, and more smartphones are being used. With this background, the need to migrate from the current E-911 service to an NG-911 service in Ecuador is more evident than ever, allowing the alerts originated in VoIP devices to be received and processed by a PSAP. Therefore, it is necessary to identify the existing technology and procedures that can be considered as a part of the next generation services, and which features are necessary to develop, include, and implement for this purpose. We next provide a summary about the international reference for the NG-911, which provide the context to clearly identify the current achievements in this direction, and the challenges that are to be faced by ECU 911 in order to pave this way.

A. INTERNATIONAL NG-911 REFERENCE

Probably the most relevant international NG-911 reference is the North-American Emergency Number Association (NENA). It is well known that NENA is at the forefront of all emergency communications, policy, technology, operations, and education issues, with a wide international presence that includes more than 11,000 members in the United States and other countries. All of these countries promote the implementation and awareness of the 911 as three-digit emergency communications systems [29]. At the same time, NENA proposes a ten-point baseline set of requirements which are oriented to consider a service as NG-911 [30], i.e., the organization needs to have raised or gained access to the following media:

1) An Emergency Service IP network (ESInet), which is an emergency system that allows any communication device from any network to make an emergency call based on IP protocol [31].
2) A Geographic Information System (GIS), which is a data creation to support DB regarding to authoritative NG-911 validation which gives the ability to control call routing below and associated management tools.
3) Caller location capabilities, which refers to the publication of authoritative NG-911 validation-related DBs for use by Originating Service Providers (OSPs) and by Location DB providers. This allows to prevalidate civic addresses, in replacement of Master Street Address Guide (MSAG), and it is supported by a Location Validation Function (LVF) and a Location for Information Server (LIS) functionalities.
4) Capabilities for state and regional routing, which consists of the publication of authoritative NG-911 routing data at state and regional levels. This functionality provides support for legacy originating services via gateways, (*e.g.*, access to traditional ALI DBs).
5) A geospatial IP control subsystem, which is related with the geospatial controlled IP software call routing functions, namely, the Emergency Call Routing Function (ECRF) and the Emergency Services Routing Proxy (ESRP).
6) Call policy routing capabilities, which is the ability to control call routing based upon a Policy Routing Function (PRF) with standardized methods in order to define, build, and control policy rules.
7) Data acquisition capabilities, which refer to additional data acquisition systems after call delivery in order to facilitate the call processing by the call-taker or by other public safety entities.
8) Call transfer capabilities, which consists of the support to the transfer of calls with accumulated call-taker notes and extended data, as well as the existence of an access key to such data to any authorized entity interconnected by ESInets.
9) Interconnection capabilities, which is the ability to interconnect with other NG-911 systems and to interact with existing and traditional E-911 systems.
10) System monitoring, which is related to the support for system monitoring, logging, or discrepancy reporting that is necessary to support troubleshooting, ongoing operation, and maintenance.

B. ACHIEVEMENTS OF ECU 911

In this subsection, we summarize several of the achievements and projects that the Integrated Security Service ECU 911 of Ecuador has implemented, and they can be considered as the starting point for an NG-911 service. Thus, in relation to the ten points indicated by NENA, Table 7 shows the state of those features in the actual ECU 911 infrastructure. Additional features that can be found in the ECU 911 are mentioned in the following paragraphs.

1) CENTRALIZED COORDINATION

ECU 911 has a singular organization model that coordinates the work of up to seven different institutions under a general

TABLE 7. Summary of the NENA NG-911 requirements with ECU 911 achievements and observations.

NENA Requirements	ECU 911	Observation
ESInet	No	Works over Telecommunication providers networks.
GIS	Yes	GIS is integrated to the PSAP technological platform.
Caller location	Partial	ALI, ANI, Geolocation of cellphone calls with variable accuracy.
State and regional routing	Yes	Providers route 911 calls to its respective regional PSAP.
Geospatial IP control	No	Needs to improve the IP infrastructure by the providers.
Call policy routing	Partial	Implemented, but no IP call origin control.
Data acquisition	Yes	Geolocation, additional data with specific ECU 911 App.
Call transfer	Yes	Functionality implemented in the 911 platform.
Interconnection	Yes	Countrywide PSAPs are interconnected and inter operable.
System monitoring	Yes	Support, troubleshooting, operation, maintenance and QoS.

direction, that allows a centralized response under standard procedures which permit an effective response and efficient usage of the scarce resources. This unusual management model has attracted the interest of similar emergency services from other Latin American countries where each institution operates separately, and they had been mentioned the interest in reply the Ecuadorian model.

2) INTERNATIONAL CERTIFICATION

The implemented management model and the operational emergency response process allowed to the ECU 911 to receive the European Emergency Number Association's Certification (EENA) in 2016 [32]. One of the most important factors considered was the continuity of the service despite the earthquake of April 2016 [10], occurred during the certification process, in which some PSAPs were affected and got out of service, and the calls were redirected to other centers, using the protocols implemented to redirect and support calls in these cases.

3) SCALABILITY

From February 2012 to December 2016, more than 62 million calls were received, and about 10.4 million events became coordinated as emergencies. Table 8 shows detailed statistics by year which are consistently increasing due to the incorporation of new PSAPs as well as peoples' trust to the ECU 911 services.

TABLE 8. Alerts received and emergencies attended by the ECU 911 service from 2012 to 2016.

Year	Alerts	Emergencies
2012	5,195,532	415,087
2013	12,384,923	1,714,891
2014	14,287,981	2,407,488
2015	16,262,726	2,954,241
2016	13,920,680	2,996,183
Total	**62,051,842**	**10,487,890**

4) INTEGRATION

According to the information available in the DB, 72% of the received alerts were made from cellphones, either low-end or smartphones, 20% were made from land-lines, 3.8% were detected by video surveillance cameras, 0.2% originated from SOS buttons, and 4% were reported through other means. The way in which alerts are reported to a PSAPs has a direct relationship with the availability of telecommunications services and new technologies in Ecuadors population.

5) LEGAL FACILITATION

ECU 911 information can be shared with the prosecutors via two methods. The first method is if the prosecutor requests information by using the SAEI-FJ platform. The second method is initiated by ECU 911 if the event recorded has criminal or legal consequences. For example, if any ECU 911 video surveillance camera captures criminal activity, the video is sent to the prosecutor. As of December 2015, up to 19,342 files were sent to prosecutors. Out of these, 1,953 were sent by ECU 911 operators after detecting an illegal activity.

6) ACCESSIBILITY

ECU 911 has developed an application for smartphones as mentioned in Section III. Thus, the user introduces personal basic information (including preexisting or special health conditions), and have the option to contact the nearest PSAP in the case of an emergency. Call-takers may acquire automatically all the personal information and the geographical location of the device at the moment that the alert message is sent. With this information, the emergency process starts and the response institutions may be dispatched, according to the type of emergency.

7) PREVENTION

With an early alert system for tsunamis and dams was implemented in 93 points of the country (81 for tsunamis and 12 for dams). This project integrates monitoring of rivers and the Pacific Ocean's level and use the information of buoys (Deep-ocean Assessment and Reporting of Tsunamis - DART), radars, seismic, hydrological stations and accelerometers, all of these was integrated in a monitoring and control platform under the control of an inter-institutional network based on the telecommunications networks used by the ECU 911 (Optical fiber, National Trunking Network, satellite and cellular). When an increase of the water level is detected, an early alert will send, allowing the population to move to safe zones and refugees. An interactive system of cameras, megaphones, solar panels, and batteries were mounted on these infrastructures and materialize the points, all the time the activity is monitored by the respective PSAP. A similar system was installed to monitoring volcanoes in eruption process, like Cotopaxi, Tungurahua, and Reventador.

8) RESPONSE TIME REDUCTION

The average response time of the FRIs for 2016 is shown in Table 9, it is given in minutes and seconds. For its calculation were considered the median time of emergencies registered in rural areas and in urban areas [10].

TABLE 9. Average response time registered for 2016.

Ord	Institution	Average Time
1	Police	09:35
2	Health Services	13:55
3	Transit	12:11

C. UPCOMING CHALLENGES

In the current technological scenario, it is important to start considering and adapting new technologies to improve emergency relief services provided by the institution. In particular, it should be considered the increasing number of smartphones that are operational in Ecuador right now. Table 10 shows the telecommunications statistics of Advanced Mobile Service in Ecuador, actualized to 2017 [33]. Thus, the following main challenges must be examined:

TABLE 10. Advanced mobile service in Ecuador by providers, showing the number of active lines for voice, voice/Internet, Internet, and data. All are distributed in a population of 16,776,977 inhabitants, resulting in an 87.33% density.

Provider	Voice	Voice/Internet	Internet	Data
Conecel	2,951,275	4,571,929	329,984	107,075
Otecel	1,485,799	2,849,177	13,906	200,142
CNT	1,012,184	1,011,198	30,885	87,850
Total	5,449,258	8,432,304	374,775	395,067
Percentage	37.19 %	57.55 %	2.56 %	2.70 %

1) ESInet

The challenge consists of migrating the actual network to an ESInet, hence introducing the capabilities to receive alert calls originated in a VoIP network, and to route them to the corresponding PSAP. To achieve this objective, it is necessary to use the Session Initiation Protocol (SIP), a packet-based signaling method which allows calls attached to audio, video, or text files. For the routing of VoIP-based emergency calls, a signaling protocol must be used, so-called Location to Service Translation (LoST) protocol, which maps the callers location to the PSAP by using the Uniform Resource Identifier (URI) to resolve the IP address of a specific PSAP to be routed [31]. Figure 7 shows the elements of the ESInet [30], and the required elements for its functionality are next listed:

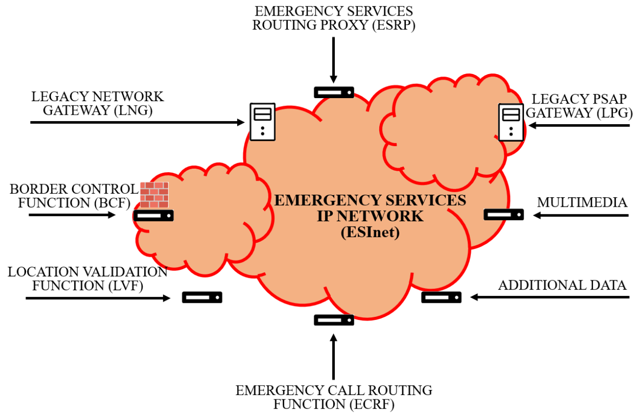


FIGURE 7. Elements of the ESInet.

- Location validation function (LVF).
- Location information server (LIS).
- Emergency call routing function (ECRF).
- Emergency services routing proxy (ESRP).
- Border control function (BCF).
- Legacy network gateway (LNG).
- Multimedia and data servers.
- A physical network for IP communication.
- Legacy PSAP gateway (LPG).

With these elements working together, a call initiated in any VoIP network will be attached to the IP address of the nearest access node and to its geographic coordinates, in order to provide the approximated caller's location.

2) IMAGE ANALYSIS SOFTWARE

Another challenge is to successfully adapt image analysis software to the video vigilance platform [34]. Considering that most cameras of ECU 911 are Pan-Tilt-Zoom, the solution will have to be implemented for such ambiance. As a first approximation, this could be done by using current image analysis algorithms and applying them at a specific time, since they do not work on video feeds where the camera lens is moving. These specific times would be fixed-lens positions on an area of interest and only do a specific analysis during that time. During these short time lapses, algorithms could be running for face recognition [35], for detection of abandoned objects at terminals, or for identifying people in threating positions at bank entrances, for example. Currently, one of the techniques of Machine Learning (ML) or Artificial Intelligence (AI) that best solves these tasks is Deep Learning, in particular, convolutional neural networks [36]. However, it is necessary to use Graphics Processing Units (GPU) to face their high computational cost. Since these tasks would have to be applied in real time or quasi-real time for the different installed cameras, a previous study has to be done to determine which is the best configuration in terms of cost-benefit to configure an AI cluster which allows to solve this issue, whose configuration parameters can be, for instance, the number and type of GPU, memory, or using hybrid multi-core CPU/GPU clusters [37].

3) BUSINESS INTELLIGENCE

An approach to business intelligence with service for emergency relief as an objective is another technological challenge to reach the status of NG-911. Through business intelligence tools such as Data Warehouses, machine learning processes, and data mining, it would be possible to achieve automatic and time-situation adaptive hot maps [38].

4) BIG DATA ANALYSIS

Another challenge is to take advantage of current and future data, which would be analyzed with big data techniques [39], and the results fed to conventional ML algorithm with two purposes. First, to have a tool by which people would be able to generate an alert to a PSAP through social media, allowing messages to reach a bot or PSAP account to attend any emergency announced by these feeds, and where pictures, videos, voice messages, and text would aid the Emergency dispatcher person. Second, to achieve a computer based system providing basic answering questions to all emergency alerters through AI, and from the gathered information generate a ticket which would be passed to the dispatching module. Basic questions would be provided to the alerter through a computer synthesized voice, in case that at any time the computer is not enough to attend such emergency, a person would take action. Since it is sometimes necessary to jointly treat all these data and they are heterogeneous in nature, it would be desirable to be able to efficiently process this data by using map-reduce techniques [40]. The application of statistical techniques and ML adapted to the map-reduce paradigm allows us to efficiently obtain useful spatio-temporal visualizations that help the manager to understand the data [27]. This type of heterogeneous data can lead to efficiency problems in structured databases. To solve this, a distributed file system or NoSQL database can be used, on which these map-reduce technologies can be efficiently applied. Given that a Data Warehouse is already available and the possibility of using a hybrid multicore CPU/GPU cluster is being evaluated, it would be interesting to integrate all these solutions [41].

The mentioned challenges will contribute to an effective ECU 911's migration towards an NG-911 service.

V. CONCLUSIONS

ECU 911 is designed to include E-911 ICTs and possibly integrate future systems. Its objective is to save lives by unifying and coordinating FRIs to increase efficiency and effectiveness of the response. The management model and information flow architecture allow the ECU 911 to receive alerts from different devices, formats, and technologies. In this model, each PSAP serves a self-contained territory and responds to emergencies in a coordinated manner with its FRIs. In the ECU 911 design, the country socioeconomic realities, available technologies, and telecommunications service accessibility levels were considered and reflected in the management model. Currently, there are 16 PSAPs and 11 DORs distributed countrywide, which have responded to more than 10 million emergencies since 2012.

Other Latin American countries such as Peru, Colombia, Venezuela, Paraguay, and Bolivia, have approached to reply the uncommon centralized management model, in their own emergencies attention services. With resolution number 27 of the Andean Parliament, it was recommended to the member countries of this international organization, to consider the management model of ECU 911 to be replicated in the Andean Region [42]. Overall results show that it is a valuable investment and service model for Ecuador and its citizens. In addition, NENA has been proposed a minimal baseline of ten points, oriented to consider a service as NG-911. The ECU 911 of Ecuador has been accomplishing an important percentage of the basic requirements and is walking to an NG-911 service. It is necessary to work in some specific points as an ESInet that allows to receive alerts from IP devices and route them to the respective PSAP, caller location, state and regional routing, and geospatial IP control.

The points implemented in the actual E-911 service in Ecuador are: *(i)* a GIS platform; *(ii)* a data acquisition system which allows to obtain the information and communicate it between FRIs while the emergency is attended; *(iii)* call transfer functionality that allows the interaction between call-takers, excepting the calls originated over an IP network (*i.e.*, Skype); *(iv)* interconnection network that allows the actual architecture of the service interact with all the PSAP countrywide, due to all of them have the same technology; and *(v)* a system monitoring platform which had been implemented in the actual management model.

All of these features let us conclude that the actual E-911 service in Ecuador has about 70% of the NENA baseline accomplished, and additionally, it has been implemented other services, not necessarily included in the mentioned list, however, they positively contribute to the migration to NG-911 services in Ecuador.

ACKNOWLEDGMENT

The authors would like to thank the ECU 911 of Ecuador for providing all the information discussed in this manuscript.

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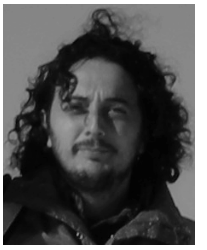

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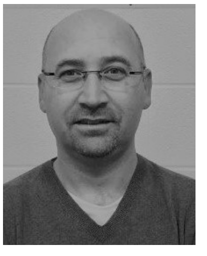

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