Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 8, No. 4, December 2020, pp.2440-2449

Telematic system for supervision and support of tactical staff involved in disaster response

Marcelo Zambrano[1 3], Edgar Maya[1], Mauricio Dominguez[1], Ana Zambrano[2], Ricardo Rosero[3]
[1] Facultad de Ingeniería en Ciencias Aplicadas, Universidad Técnica del Norte, Ibarra-Ecuador
[2] Departamento de Telecomunicaciones y Redes de Información, Escuela Politécnica Nacional, Quito-Ecuador
[3] Departamento de Investigación, Tecnológico Superior Rumiñahui, Sangolquí-Ecuador

ABSTRACT

This paper describe the design and implementation of a Telematic System that aims to supervision and support tactical staff involved in disaster response operations. Each tactical group member carries a programmable electronic module that allows obtaining information about the state of the environment (temperature, humidity, hot spots, air quality, etc.) and itself (position, emergency signal, heart rate, etc.). The information collected is sent to a data server through a wireless network based on LoraWAN technology, where it is stored and processed to obtain different types of reports that allow to plan the response operations and make decisions according to reality. To test the system functionality, a prototype was implemented based on the architecture described in this paper. The results were satisfactory, obtaining effective, permanent and real-time communication between tactical staff within the disaster-affected area and strategic staff responsible for decision-making outside of it.

Keywords: Disaster Response, IoT, LPWAN, LoRaWAN, Sensors Networks, Command and Control Systems

Corresponding Author:

Marcelo Zambrano
Facultad de Ingeniería en Ciencias Aplicadas, Universidad Técnica del Norte
Av 17 de Julio 5-21, Ibarra
E-mail: omzambrano@utn.edu.ec

1. Introduction

When a disaster occurs, the agencies responsible for citizen security (Police, Fire Department, Civil Defense, Red Cross, etc.) send their tactical staff to the area affected by the incident with the aim of mitigating their destructive effects and minimize possible environmental, material and human losses [1] [2]. Within the zone of the incident, the response staff are exposed to many risks that threaten their physical integrity and even their lives: fires, toxic gases, landslides, sharp materials, explosions, etc. For this reason, it is essential to provide them with relevant information about the situation state that would enable them to fulfill their mission and face the existing risks in the best possible way [3] [4].

In order to carry out effective disaster management, is important to have a precise and timely environment situational awareness, which allows operations planning and decision-making in accordance with reality. First responders must maintain permanent and real-time communication with their peers both within the affected zone and with the strategic staff responsible for the mission outside it. On the other hand, permanent monitoring of the operating environment is also necessary, which allows the information obtained by tactical staff and / or any other type of reliable information source (sensor networks, drones, affected, etc.) to be made available to strategic staff [5] [6].

Currently, at least within the Latin American context, there is no tool that let to provide support to tactical staff involved in a disaster response operations. This paper describes the design and implementation of a Supervision and Support Telematic System (SS-TELSYS), which enables the acquisition of a real-time and accurate situational awareness of the incident and also the supervision of tactical staff within the affected area. In general, the system establishes a tactical network that enables communications between the response personnel (both tactical and strategic), as well as the supervision of different types of parameters that allow a mental representation and the understanding of the situation.

1.1. State of art

The main advantage of SS-TELSYS over other similar solutions is in its agility (opportunity, portability and flexibility) and low implementation costs. Similar solutions like AF3 [1], Similar solutions like AF3, are very efficient but with very high implementation costs, especially for countries with limited resources such as Ecuador; this causes that despite its high performance, it has not yet been implemented on a practical level. Systems such as COORCOM [2], ECHO [3] or ECU911 [4], use portable radios under protocols such as APCO 25 [5], TETRA [6] o TETRAPOL [7], Systems such as COORCOM [8], ECHO [9] or ECU911 [10], use portable radios under protocols such as APCO 25 [11], TETRA [12] or TETRAPOL [13], allowing to obtain information about the situation and communications with the tactical staff within the disaster area. However, the information that can be obtained through the audio messages exchange is limited and does not allow the formation of an accurate knowledge of the operations environment; for example, how a firefighter could report his exact position (or of an affected) to his supervisor in a hostile environment such as a fire, with poor visibility, fire, high temperatures, toxic gases, etc.

SS-TELSYS has been developed based on current IoT technologies, which are characterized by their sensorization and communication capabilities, low energy consumption and relatively affordable implementation costs. Their main contribution is in its capability to describe the situation state, obtaining relevant information about the operations environment (environmental temperature, humidity, air quality, hot spots, danger zones, etc.) and the first responders (identification, position, route, blood pressure, etc.). A wireless network implemented under LoRa (Long Range) technology [8], shapes the system's communications backbone, allowing the mobility and peer-to-peer communications within the incident area and strategic personnel out of it.

LoRa belongs to the technologies group defined as Low Power Wide Area Network (LPWAN), that is, long-range wireless networks with low power consumption [9]. LoraWAN is the Data Link Layer protocol (model OSI layer 2), describes the architecture and the technical and functional specifications for the implementation of a network under LoRa technology. The network architecture defines a star-type topology in which each end node can communicate with one or more gateways, which in turn communicate with a network server (Figure 1).

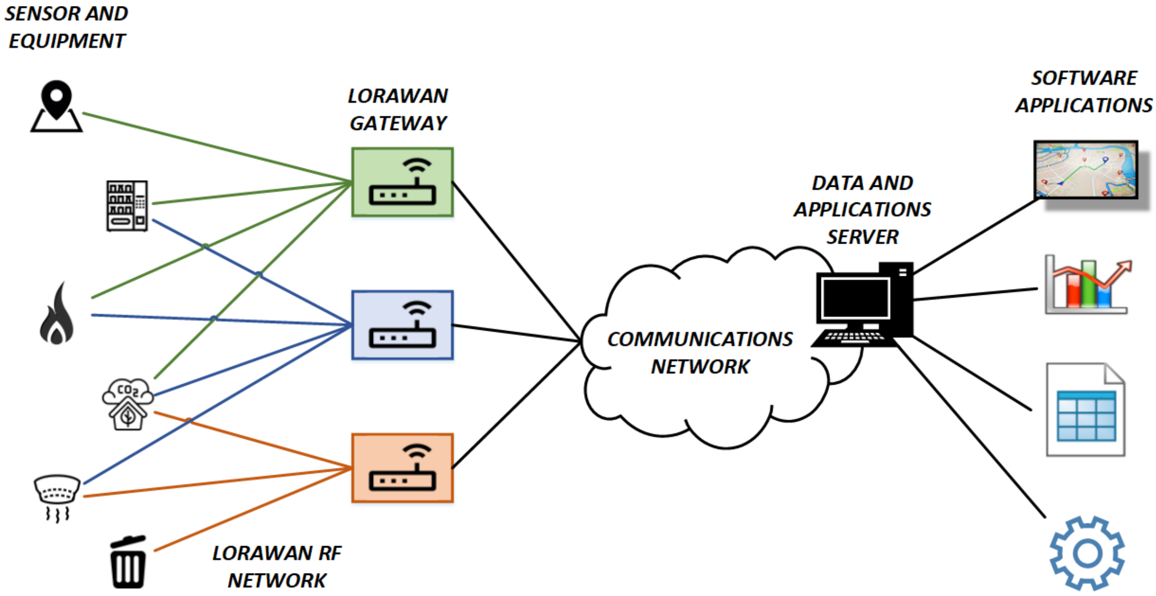


Figure 1. LoraWAN network structure [10]

LoRa is an excellent alternative for the implementation of command and control systems and tracking for moving assets, due to its great reach, symmetry and two-way communication. Among its disadvantages we can mention the need for line of sight between nodes, the use of gateways and its small bandwidth, which generally limits its reach towards IoT applications and sensor networks [11] [10].

2. Material and methods

SS-TELSYS is designed based on a distributed architecture that allows obtaining the adaptability and scalability necessary to operate in critical environments such as a disaster (unstable, with unfavorable operating conditions and high-risk). It is made up of two types of nodes: user and infrastructure.

User nodes are responsible for allowing communication between response staff and obtaining the information required to shape accurate and timely situational awareness. They are based on the Sensorization and Supervision Programmable Electronic Module (SS-PEM), which in turn is made up of:

- A lithium battery (3 cells and 7.5 volts) that delivers all the energy required by the electronic components and makes their portability possible.
- A sensors and actuators set that deliver the information required to form an accurate and real-time situation image (position and biometric data of the tactical staff, telemetric marks, distress signal, ambient temperature and humidity, air quality, etc.).
- A LoraWAN communication interface that allows the communication of each brigade member with their peers and with strategic personnel outside the disaster area [16].
- Finally, an Arduino module integrates the electronic and communications part, providing the necessary control to filter and organize the data obtained (format, periodicity, type of data, etc. Figure 2 shows an overview of the SS-PEMs architecture.
-

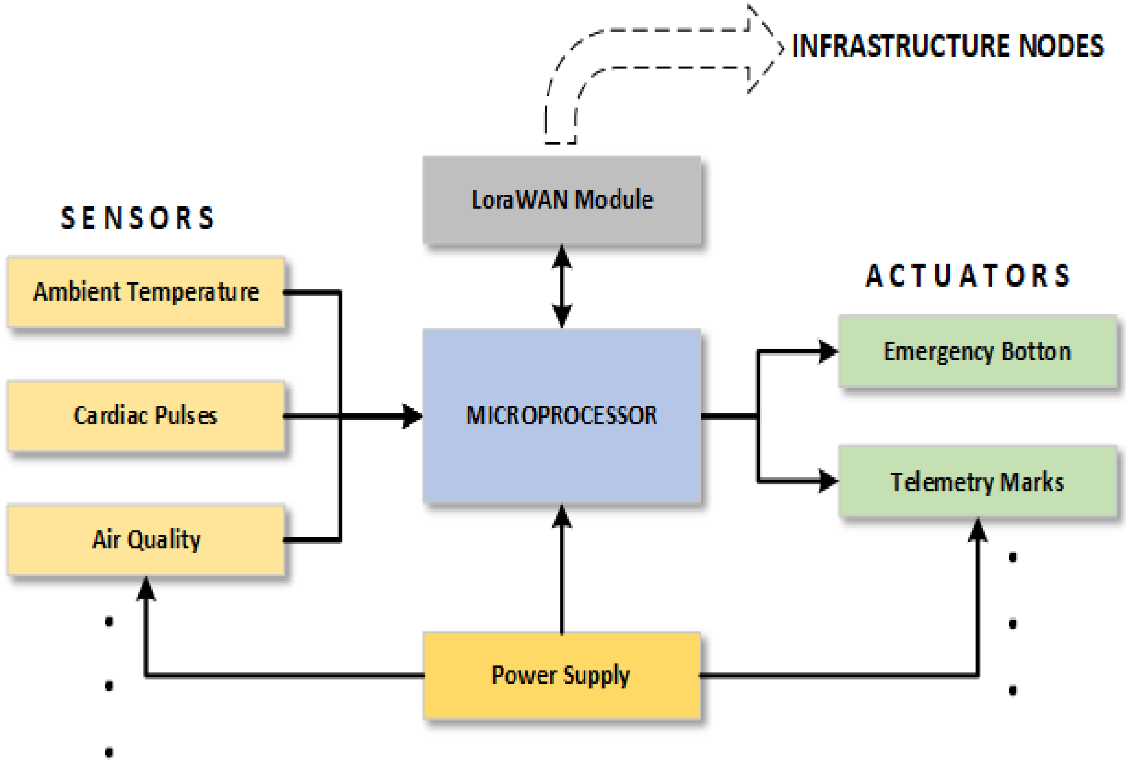


Figure 2. SS-PEM block diagram

Like user nodes, infrastructure nodes are portable (powered by two lithium batteries) and are essentially made up of LoraWAN gateways. LoraWAN gateways operate as network access points for the SS-PEMs (LoraWAN radios), transmitting or receiving information bidirectionally from or to user nodes under their jurisdiction. Depending on the type and model, a LoraWAN Gateway can manage approximately 1,000 nodes by sending permanent information in real-time, and having one (single-channel) or eight (multi-channel) simultaneous communication channels [14] [17]. Figure 3 shows an overview of the Infrastructure nodes architecture.

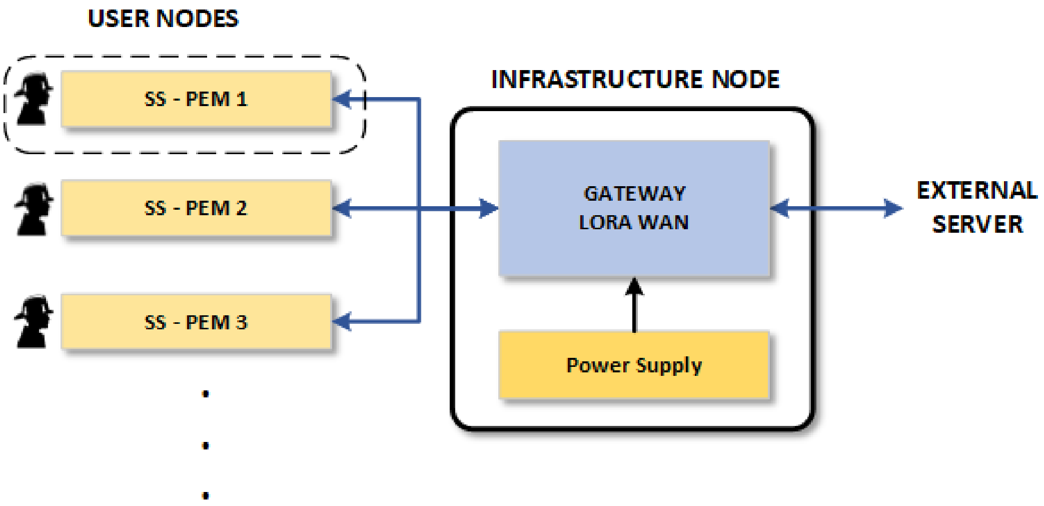


Figure 3. Infrastructure node block diagram

Each response team member within the disaster zone behaves like a user node, and therefore, must carry a SS-PEM that allows them to collect and send information about their state and that of the operations environment. The infrastructure nodes must be located at geographically strategic points that allow maintaining line of sight with all the user nodes, and can be located on land, sea or air.

The infrastructure nodes operate as transparent gateways, transmitting to an external data server, in real-time and by any available communication medium (WiFi, mobile data service, radio or satellite links, etc.), all the data sent by the user nodes. LoRaWAN gateways have to be considered as having limited computing capacity, so the organization and processing required to transform the data into useful information has to be transferred to the external data server. The data server must be located in a secure area that has all the technological infrastructure to guarantee the availability and access to information at all times and by any system user that requires it.

As a complement, a web application will allow system users, both internal and external, to learn about the state of the situation through different reports types, graphs and statistics, generated from the information stored in the aforementioned external server. Figure 4 shows the basic architecture of the SS-TELSYS.

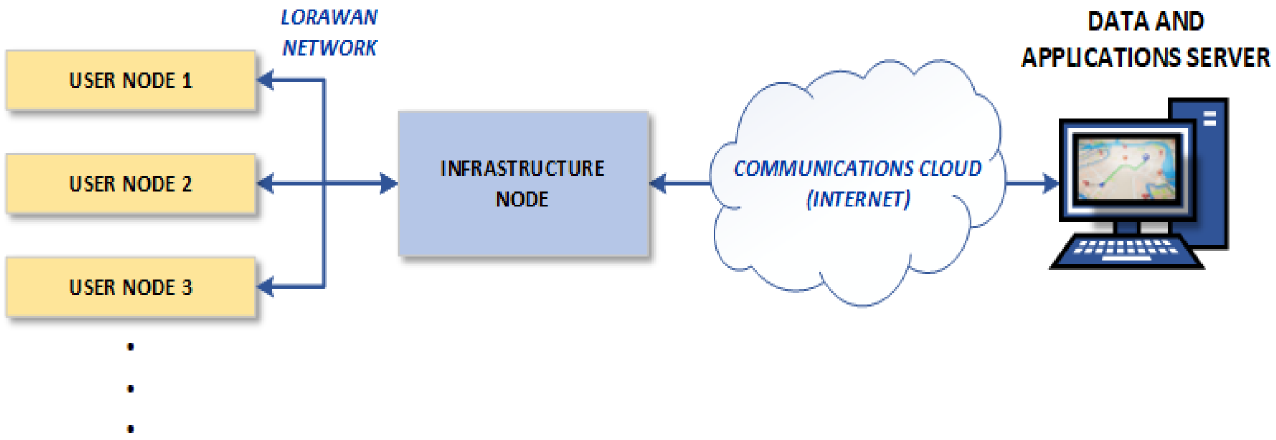


Figure 4. SS-TELSYS basic architecture

Although the LoraWAN technology allows a coverage range of several kilometers (theoretical 15 km with line of sight), if necessary, the network can scale including one or more infrastructure nodes, forming a backbone network that allows to expand the supervised area or cover possible dark areas.

The data acquired by each of the SS-PEM is sent to any of the infrastructure nodes implemented, may be the case that a user node is subscribed to more than one infrastructure node at the same time; In this case, the data server will be responsible for filtering and discriminating the data received so that there is no duplication. Figure 5 and 6 show, respectively, the extended system architecture and a general outline of the proposed solution.

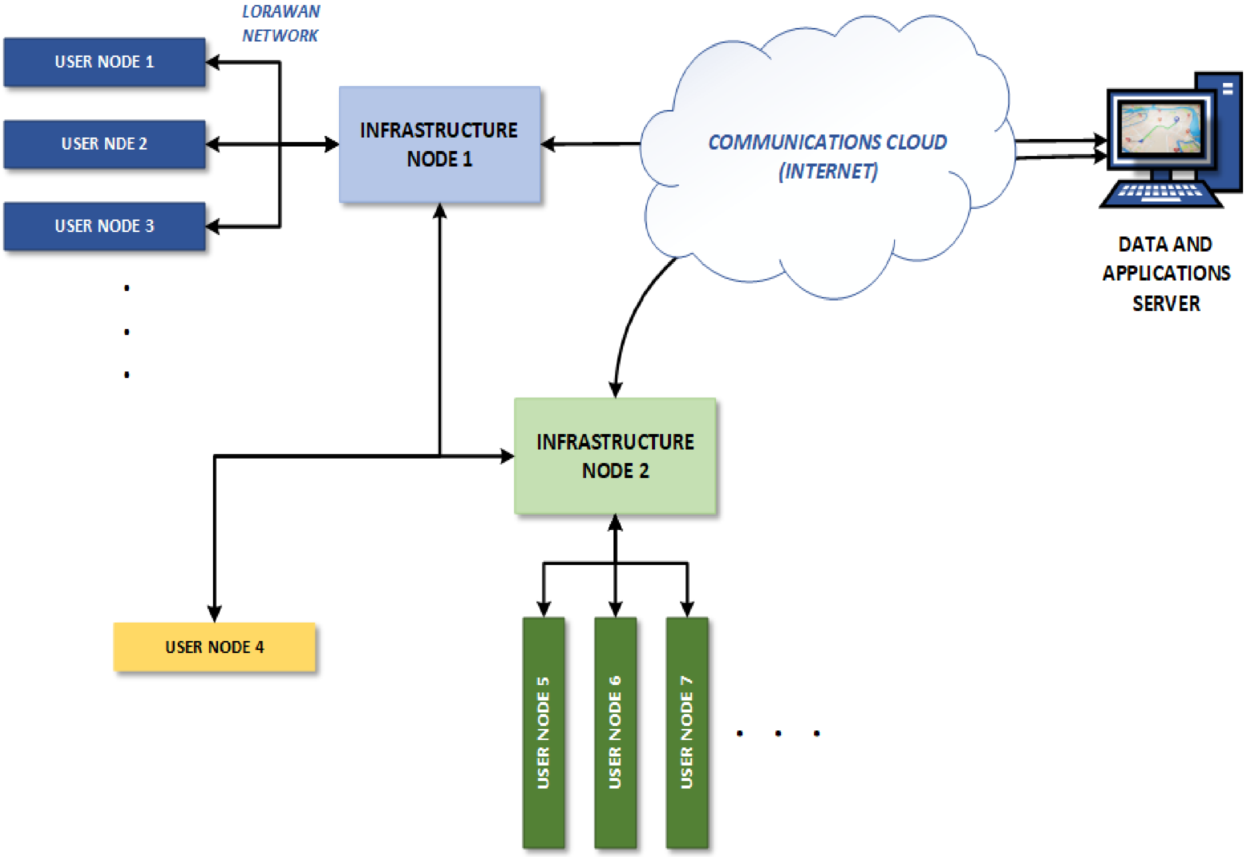


Figure 5. SS-TELSYS extended architecture

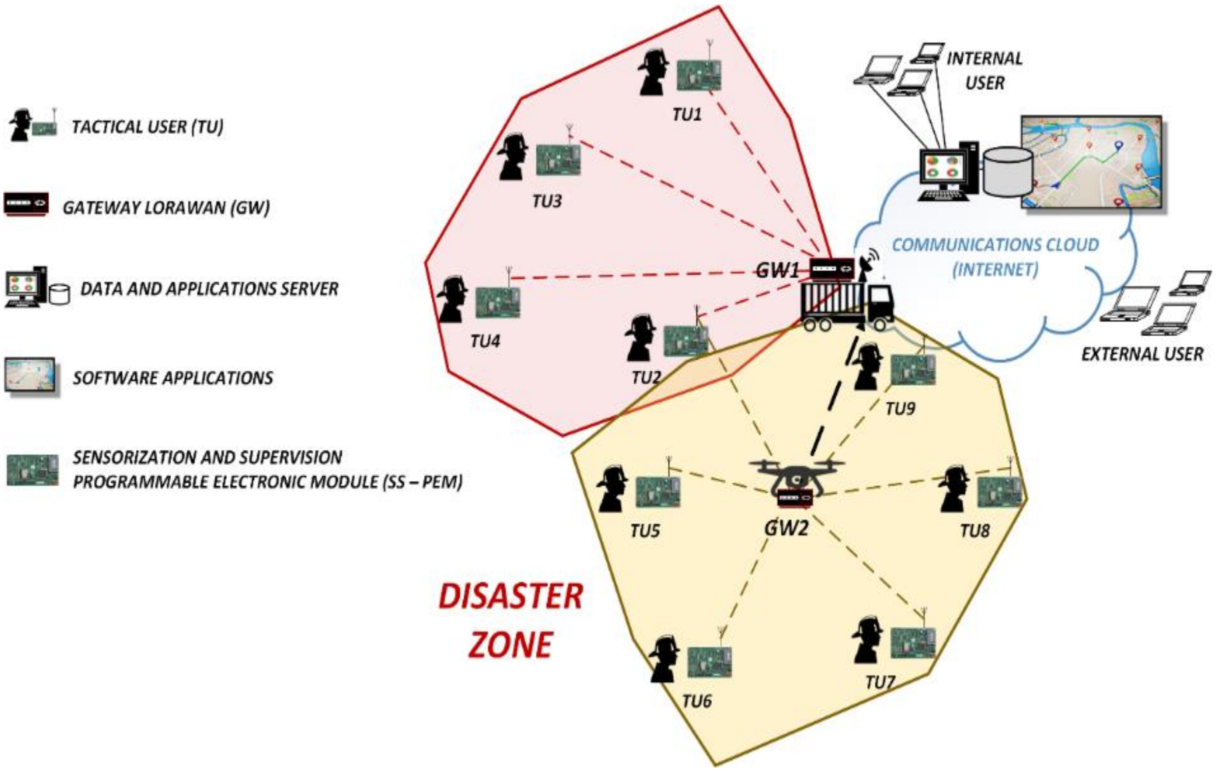


Figure 6. SS-TELSYS general scheme

2.1. Data management

The data received from the user nodes, through the SS-PEM, are sent to the infrastructure nodes by means of a frame with the following generic structure (Figure 7).

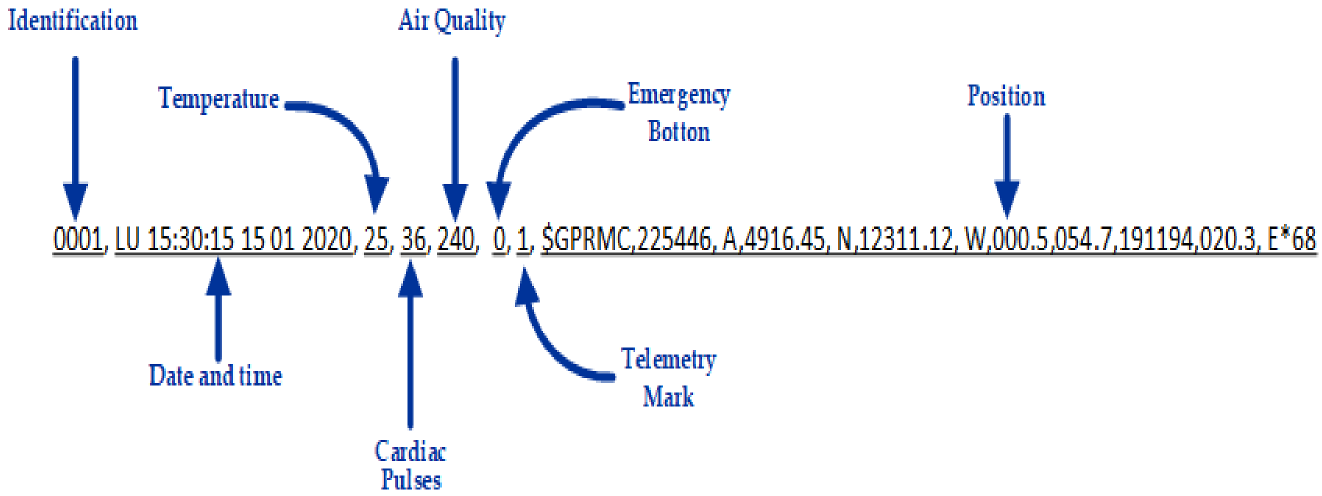


Figure 7. SS-TELSYS frame scheme

Each SS-PEM has a code that identifies it and univocally differentiates it from the other SS-PEMs enabled in the system. This code heads the data frame, preceded by the time, date and data from the different sensors by which the programmable module is equipped, allowing its characterization and subsequent recovery.

From the infrastructure nodes, the data is sent to the Server in the same frame format mentioned above, and this is where they are ordered, filtered and grouped according to a predefined information model of the JSON type (JavaScript Object Notation) [18], in which, the hierarchical levels and attributes of each object are defined. JSON has been chosen as the format for data management due to the syntax simplicity, easy of processing and especially, considering the future interoperability of SS-TELSYS with other IoT systems and platforms in the cloud. The stored data will make it possible to obtain different types of reports such as movement history (of all or each specific staff member), heat maps (temperature, humidity, air quality, etc.), event logs, etc.

The data sending timing can be configured at the discretion of the system managers and according to the criticality of the emergency, being able to be carried out periodically (according to a pre-established frequency) or on demand.

The SS-TELSYS has been designed based on a modular architecture that allows the easy and fast updating and / or modification of any of its components, as well as the incorporation of new functionalities. Although the system is flexible enough to operate with any database engine, the system is thought and designed to operate in conjunction with other systems and platforms in the communications cloud, therefore, is suggested to use Cloud-type databases, such as Amazon Aurora [19], Firebase [20], Cloud SQL [21], DynamoDB [22], among others.

3. Results and Discussion

To verify the SS-TELSYS functionality, tests were carried out on a prototype developed based on the architecture described in this paper, with two user nodes implemented based on LoRaWAN transceivers, model SX1278 [23]; and an infrastructure node implemented based on a single-channel LoRaWAN Gateway, model LG01-N [24]; both brand DRAGINO and operating in the 915 MHz band. The data server was implemented on a virtualized HOST, with a CentOS version 7 Operating System [25] and Firebase as real-time database, both on the Google Cloud Platform [26].

The scenario of an urban-forest fire was taken as a case study, equipping the SS-PEMs with sensors of temperature, humidity, positioning (GPS) and an emergency button (Figure 8).

Figure 9 shows the structure of the SS-TELSYS Firebase database.

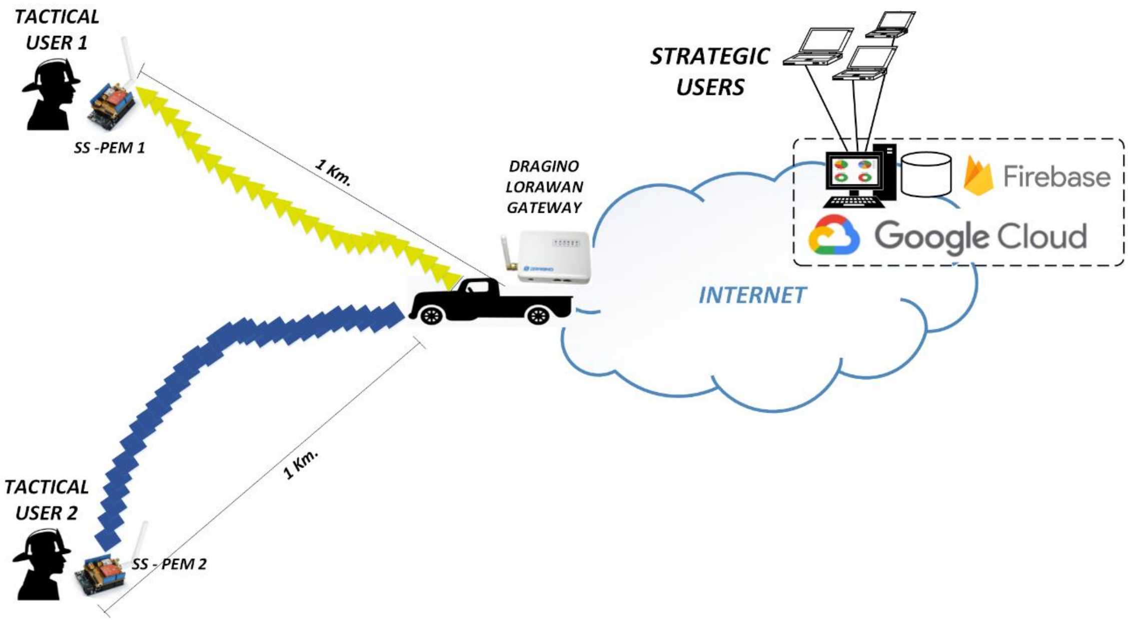
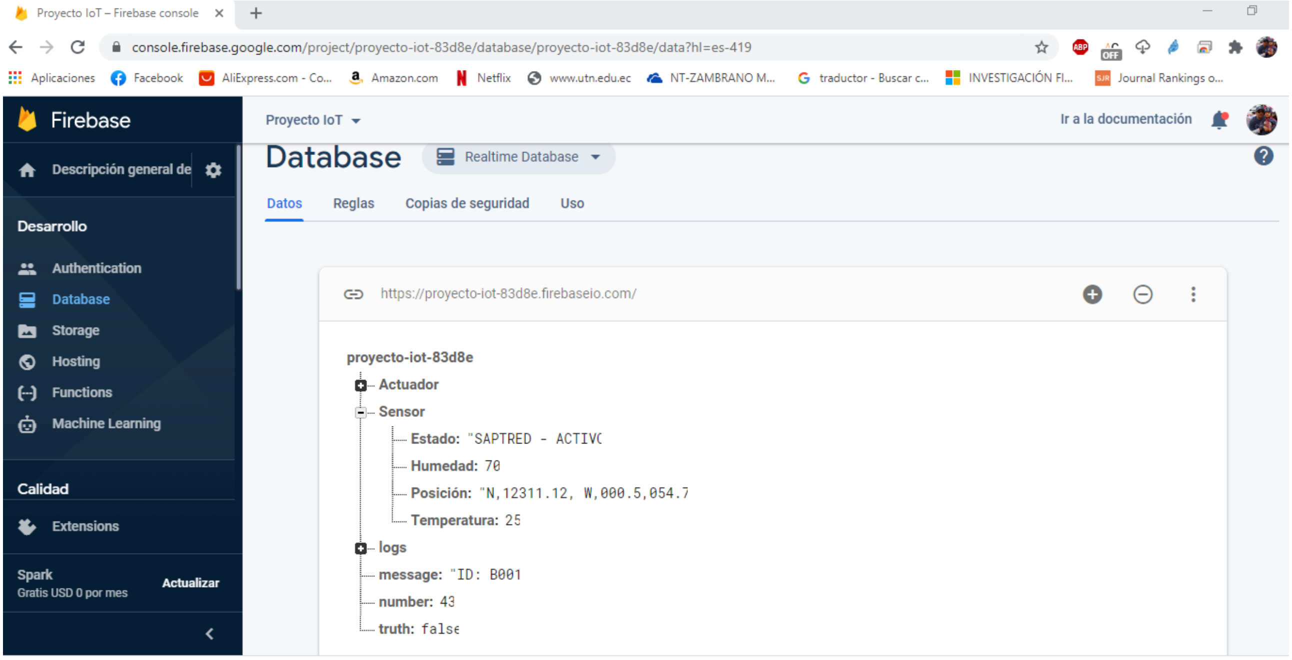


Figure 8. Test scenario



```
proyecto-iot-83d8e
 ⊞- Actuador
 ⊟- Sensor
     Estado: "SAPTRED - ACTIVC
     Humedad: 70
     Posición: "N,12311.12, W,000.5,054.7
     Temperatura: 25
 ⊞- logs
  message: "ID: B001
  number: 43
  truth: false
```

Figure 9. SS-TELSYS - Firebase real-time database

The results obtained were satisfactory. Permanent communication could be maintained between the data server, the infrastructure node and the user nodes; the data collected by each of the SS-PEMs was successfully sent to the Firebase database, even in urban environments where there were other wireless signals operating at the same frequency. The network performance was decreasing in inverse relation to the increase in the distance between the user nodes and the infrastructure node, reaching an acceptable quality in communications at a distance of approximately 1000 m, with a loss of packets that oscillated between 20% and 25%.

Figure 10 shows some graphic reports obtained from the Data and Applications Server. The information comes from the temperature and humidity sensors and emergency button of the SS-PEM 1.

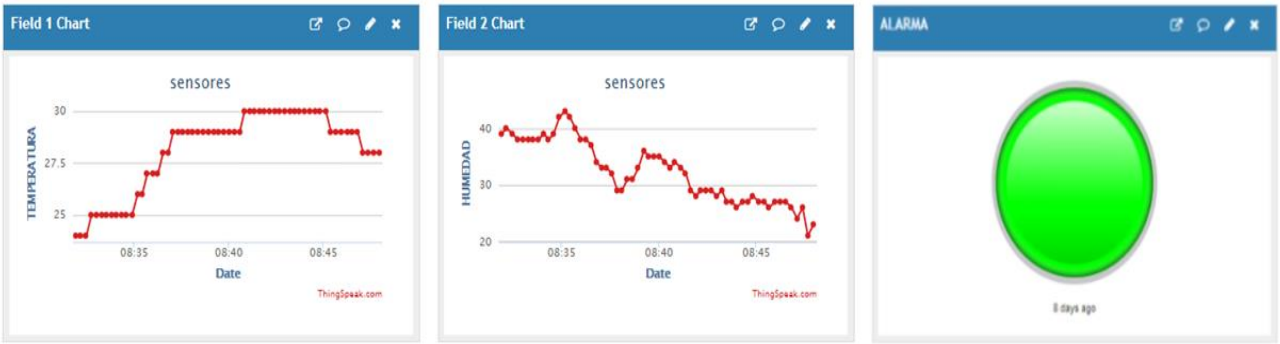


Figure 10. SS-TELSYS graphic reports

The imperative need to maintain line of sight between infrastructure nodes and user nodes must be emphasized. At very short distances (less than 100 meters), effective communication could be maintained without line of sight and with acceptable losses, which opens the possibility for new research and development for indoor positioning applications. At distances greater than 100 m. without line of sight, the situation is very different, immediately began to have significant losses that prevented tracking and communication with the SS-PEMs.

4. Conclusions

This paper describes the design and implementation of a Telematic System that aims to supervise and support tactical staff involved in disaster response operations (SS-TELSYS). Through a programmable electronic module, that each first responder carries with them (SS-PEM), the system obtains the necessary information to create an accurate and timely situation awareness. The data obtained by the SS-PEMs is sent, in real-time, to a Data Server through a deployable network (portable, mobile and scalable) based on LoraWAN technology. In the Server, the data is stored and processed to obtain relevant information about the state of the affected area and the tactical staff members within it, making it possible to plan operations and make decisions in accordance with reality.

The validation of the system functionalities was carried out by means of tests on a prototype implemented based on the architecture described in this article and within a simulated scenario for an urban-forest fire, with two user nodes and one infrastructure node, installed on LoraWAN technology. Real-time measurements of ambient temperature and humidity, users' position and the activation of an emergency signal (button incorporated in the SS-PEMs) were taken. The information was successfully collected and transmitted to a data server located on the Google Cloud Platform, where, using the available statistical tools, different types of reports could be generated to monitor user's position in real-time and perform a post-disaster analysis of the activities carried out by them.

The architecture flexibility in terms of its scalability and parameters to be monitored could be verified. The incorporation of new users is carried out automatically, provided that the brigade member carries a SS-PEM. The sensors incorporated can vary according to the need and type of disaster.

LoraWAN was selected as a technology for communications, due to its low power consumption (which facilitates its portability), great range and tolerance to interference. Within its limitations, it can be mentioned its low bandwidth (which makes it impossible to transmit audio and video in real-time) and the need for line of sight between the transceivers and the communications gateway. It is important to consider that in a real scenario for a disaster, the conditions are always dynamic and unexpected situations can be much less friendly. This is where a portable, scalable and with mobile users network presents its real benefits.

Regarding future work, a software-level module is being developed that allows sending pre-programmed messages, to and from the tactical staff; short text messages, which allow alerting or giving specific instructions to the brigade members or vice versa, for example, hot spots (geo-referenced points to avoid), interest points (points to which they have to travel to assist a victim or partner in trouble), orders, alert messages, plans change, etc. Also, other communication technologies are being investigated that allow the audio and video in real-time exchange and greater resilience in the event of failure of any of the communication equipment.

References

[1] Secretaría Nacional de Gestión de Riesgos y Desastres, “Plan de Respuesta,” 25 Mayo 2020. [En línea]. Available: https://www.gestionderiesgos.gob.ec/plan-de-respuesta/.

[2] The International Federation of Red Cross and Red Crescent Societies, “Regional and international disaster response tools and systems,” International Federation of Red Cross and Red Crescent Societies, 2020.

[3] Božović Marijola, Mihajlović Emina, Ilić-Krstić, Ivana Živković, Snežana, “INSTITUTIONAL FRAMEWORK FOR ACCIDENT MANAGEMENT: A CASE STUDY IN FIRE RESCUE BRIGADES PRACTICE,” Facta Universitatis, Series: Working and Living Environmental Protection, 2019.

[4] Alexander DA, Klein S. “First responders after disasters: a review of stress reactions, at-risk, vulnerability, and resilience factors. Prehosp Disaster Med.” 2009;24(2):87-94. doi:10.1017/s1049023x00006610

[5] Y. Usuda, T. Matsui, H. Deguchi, T. Hori, and S. Suzuki, “The Shared Information Platform for Disaster Management –The Research and Development Regarding Technologies for Utilization of Disaster Information–,” J. Disaster Res., Vol.14, No.2, pp. 279-291, 2019.

[6] S. Ahmed, M. Rashid, F. Alam and B. Fakhruddin, "A Disaster Response Framework Based on IoT and D2D Communication under 5G Network Technology," 2019 29th International Telecommunication Networks and Applications Conference (ITNAC), Auckland, New Zealand, 2019, pp. 1-6, doi: 10.1109/ITNAC46935.2019.9077975.

[7] Europena Commission, “Advanced Forest Fire Fighting” 5 June 2017. [En línea]. Available: https://cordis.europa.eu/project/id/607276/es.

[8] Carmenta, “Carmenta CoordCom” 2020. [En línea]. Available: https://carmenta.com/en/public-safety/carmenta-coordcom-2/.

[9] THALES Group, “Emergency and Crisis,” THALES Group, 2020. [En línea]. Available: https://www.thalesgroup.com/en/worldwide/security/echo.

[10] Gobierno de la República del Ecuador, “Servicio Integrado de Seguridad ECU-911,” 2020. [En línea]. Available: https://www.ecu911.gob.ec/.

[11] Ramsey, Eric Rene. “A software based APCO Project 25 data transmission base station for local police headquarters.” 2007.

[12] ETSI, “Terrestrial Trunked Radio (TETRA),” 2019.

[13] Bârcă, Claudiu Dan. “TETRA SYSTEM-OPEN PLATFORM-INTEROPERABILITY AND APPLICATIONS.” 2017.

[14] R. Kirichek, V. Vishnevsky, V. D. Pham and A. Koucheryavy, "Analytic Model of a Mesh Topology based on LoRa Technology," 22nd International Conference on Advanced Communication Technology (ICACT), Phoenix Park, PyeongChang,, Korea (South), pp. 251-255, 2020, doi: 10.23919/ICACT48636.2020.9061519.

[15] Chaudhari, B.S.; Zennaro, M.; Borkar, S. LPWAN Technologies: Emerging Application Characteristics, Requirements, and Design Considerations. Future Internet, 12, 46, 2020

[16] Medium.com, “Haciendo IoT con LoRa: Capítulo 1.- ¿Qué es LoRa y LoRaWAN?,” 2020. [En línea]. Available: https://medium.com/beelan/haciendo-iot-con-lora-cap%C3%ADtulo-1-qu%C3%A9-es-lora-y-lorawan-8c08d44208e8.

[17] The Things Network, “LoRaWAN,” 2020. [En línea]. Available: https://www.thethingsnetwork.org/docs/lorawan/.

[18] Java Script, “Introducing JSON,” 24 06 2020. [En línea]. Available: https://www.json.org/json-en.html.

[19] Amazon, “Amazon Aurora,” 20 05 2020. [En línea]. Available: https://aws.amazon.com/es/rds/aurora/.

[20] Google, “Firebase,” 11 05 2020. [En línea]. Available: https://firebase.google.com/?hl=es-419.

[21] Google, “Cloud SQL,” 01 07 2020. [En línea]. Available: https://cloud.google.com/sql/?&utm_source=google&utm_medium=cpc&utm_campaign=latam-LATAM-all-es-dr-skws-all-all-trial-e-dr-1008075-LUAC0009296&utm_content=text-ad-none-none-DEV_c-CRE_431408636335-ADGP_SKWS+%7C+Multi+~+Storage+%7C+SQL-KWID_4370004294598233.

[22] Amazon, “DynamoDB,” 01 07 2020. [En línea]. Available: https://aws.amazon.com/es/dynamodb/.

[23] DRAGINO, “LoRa GPS Shield for Arduino,” 2020. [En línea]. Available: https://www.dragino.com/products/module/item/108-lora-gps-shield.html.

[24] DRAGINO, “LG01-N Single Channel LoRa IoT Gateway,” 2020. [En línea]. Available: https://www.dragino.com/products/lora/item/143-lg01n.html.

[25] CentOS Project, “The CentOS Project,” 26 June 2020. [En línea]. Available: https://www.centos.org/.

[26] Google, “Google Cloud Platform,” 05 January 2020. [En línea]. Available: https://cloud.google.com/?&utm_source=google&utm_medium=cpc&utm_campaign=latam-LATAM-all-es-dr-bkws-all-all-trial-e-dr-1008075-LUAC0010197&utm_content=text-ad-none-none-DEV_c-CRE_382276148618-ADGP_BKWS+%7C+Multi+~+Google+Cloud-KWID_43700047166266644-kwd-3.

[27] Oracle, “Java,” 03 March 2020. [En línea]. Available: https://www.java.com/es/.

[28] Google, “Angular JS,” 20 09 2029. [En línea]. Available: https://angularjs.org/.