An MQTT approach for fire brigades monitoring in prevention and suppression activities: A case study for the Natural Protected Area "Sierra de Guadalupe", Mexico.

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Abstract

Forest fires constitute a constant hazard for natural protected areas in Mexico, especially during dry seasons and near urban areas. Unplanned fires can escalate quickly, necessitating prompt human intervention through the dispatch of highly trained fire brigades, the allocation of available transportation resources, and seamless coordination, communication, and asset tracking. Given that forests span extensive areas with complex topography, human resources become a high-value asset for fire management. Ensuring precise control and safety is paramount during emergency responses, where location and communication are critical for effective coordination and management of the limited resources. This paper presents a tracking and monitoring system designed with off-the-shelf technologies, focusing on personnel and based on the Message Queue Telemetry Transport (MQTT) protocol for efficient message exchange. The system leverages existing mobile technologies with cellular connectivity, with a custom platform providing location information about fire brigades, individuals, and their current status to fire managers. Gathered data is integrated cartographically through a WEB mapping platform with content suited for fire management, bringing up-to-date fire brigade movements, providing per-unit status, and enhancing situational awareness. The results are compared with traditional two-way radio methodologies.

1. Introduction

Wildfires pose a significant threat to humans due to various factors, including proximity to urban areas, the high availability of forest fuel, pollution, the loss of natural resources, including animal and vegetal species, as well as the loss of human lives and damage to built infrastructure. Fire constitutes one of the significant factors contributing to biodiversity loss in Mexico, resulting in a fragmented landscape through the reduction of native vegetation, soil degradation, and the loss of ecological services (SEDEMA, 2020).

Fire management, as an integral part of forest management, demands human and material resources to be allocated to address various activities, including the prevention and suppression of fires. Under this study, a protocol for fire management exists (SEDEMA, 2019), providing legal, administrative responsibilities and boundaries for the three levels of government involved in the study area. The central premise of such a protocol is the safety of the involved personnel at all times, and identifying all required resources to guarantee a quick and effective response with the involved actors towards wildfires.

Given the aforementioned fire protocol, well-established steps are defined and guide the fire outbreak. The protocol provides a situation assessment guideline based on the number of required brigades and time for their suppression. A wrong estimation can leads to escalating events, with an increased time frame, more allocated personnel and further resources. Fire suppression should be done promptly and with full knowledge of the personnel status, location, and related fire equipment, which is susceptible to damage and wear due to extreme conditions.

Fire suppression relies on tracking assets based on their location and the communication of their current status. Location is relevant to understand the proximity to an event, the amount of forest fuel, nearby black lines available used to stop spreading fire, reachability, and even proximity of the closest resources available, like water, transportation, and specialized fire equipment. As such, communication is essential to track the progress of fire brigades and share information regarding the fire event.

From such a perspective, human resources are limited when problems arise spanning large areas, and tracking resources becomes crucial, especially in the middle of emergencies with changing conditions. Forest firefighters are highly specialized professionals responsible for preventing, combating, and extinguishing wildfires in high-value environmental areas with rapidly changing conditions. Forest Firefighters are different from urban firefighters, with specialized equipment, training, action protocols, and physical condition.

Typically, most activities are carried out in a rough landscape and tracked with the help of two-way radio communication devices and a central radio base. However in the absence of a line of sight, communications cannot be correctly performed. To alleviate the situation, a monitoring solution for tracking fire brigades is presented, making use of available cellular networks and off-the-shelf technologies, implemented, tested, and compared with traditional radio communication to improve the tracking and monitoring tasks.

1.1 Study Area

Mexico City takes control of 27 Natural Protected Areas (ANP), from which one federal ANP, "Parque Nacional el Tepeyac", and two local ANPs, "Sierra de Guadalupe" and "La Armella", correspond to the study area. The dominant vegetation cover in the study area corresponds to xerophytic scrubs, oak/pine forests, low vegetation, along with endemic species adapted to dry climates, including "Copal", "Cazahuate", "Huizache", "Tepozan", "Maguey", "Nopal", and many cactus plants. Invasive species like "Eucaliptus" also play a significant role in the overall health of vegetation, carrying diseases, and increasing forest fuel availability. Regular activities are carried out to preserve protected species, reduce imbalances due to invasive plants, and control spreading diseases.

1.2 Historical Fires

From 2019 to 2024, wildfires have affected large forest extensions within the study area, but a decrease in burnt regions has been achieved per year, ranging from 180ha down to 15ha, based on prevention activities totalling 15 km of controlled black lines and 30 km of firebreak gaps, in addition to 1.7 km of reconditioned access roads. Such interventions are related to faster response to fire outbreaks and actions to prevent uncontrolled wildfires. Figure 1 depicts actual fire events in a two-year period, showing high fire activity, the complexity of the Mexico City basin, and the proximity to urban areas.

Education also plays a significant role in wildfire reduction as the community becomes involved by watching and making reports using social network platforms, sharing photographs and notifications over suspicious fire events.

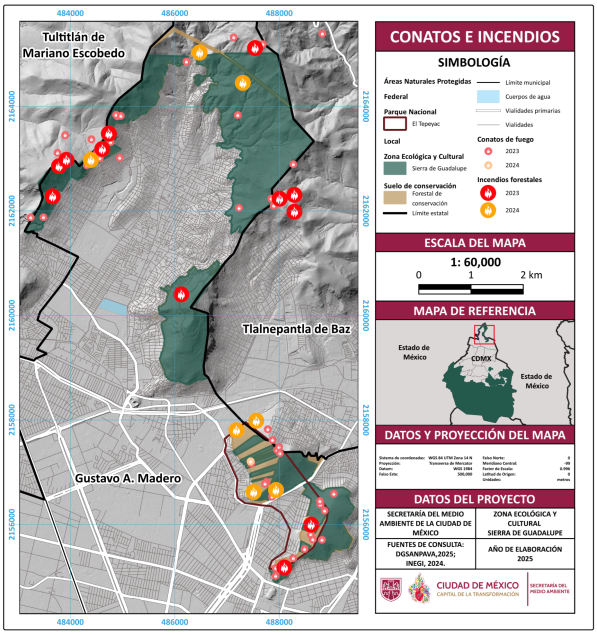

Figure 1: The map of the study area shows in green the location of past fire outbreaks and actual fires between 2023 and 2024. Map Source: SEDEMA, 2025.

Prompt attention towards fire outbreaks requires effective detection and communication, constant tracking, and resource allocation of both human and material resources. The former resources consist of highly trained forest fire brigades, while the latter are composed of specialized tools, communication devices, transportation, and water provisions, both for personnel and for the fire equipment, including drinking water.

Mitigation involves deploying effective strategies to halt the spread of fires, identifying their geographic extent, facilitating communication among actors, and dispatching brigades based on criteria such as local weather conditions, topography, accessibility, the event's magnitude, and transportation options.

1.3 Fire suppression protocol

Under the case study, an existing fire protocol(SEDEMA, 2019) considers multiple fire types based on their severity and complexity. As the fire complexity increases, more resources are allocated, including more brigades, water supplies, attention time, and further status updates. Table 1 shows a brief overview of the requirements per event complexity, showing how resources almost double per increasing level. Of course, the main goal is to avoid escalation and preserve personnel integrity. Due to the proximity to urban areas, a wide urban-forest interface exists, so events are prone to scale up and involve other government agencies, as damages may increase and human lives are at greater risk. Personnel safety, as a protocol's priority, restricts the allocated time for each fire brigade per journal.

Severity Level	#Brigades	Allocated Time (h)
5	1-7	0-2
4	8-16	2-5
3	16-35	5-48
2	36-50	48+
1	50+	48+

Table 1: Fire Severity types with estimated allocated hours and brigade numbers. Higher Severity corresponds to Level 1.

1.4 Communication codes

Radio communications in this context employ a set of radio codes ranging from 00 to 100, used to provide brief information between brigades, radio operators, and fire managers. Typical codes are 20 (requesting status update), 21 (no news), 62 (fire), 84(request integration to current activities or help with visual inspection by foot), 87 (Requested support), 96 (false alarm), and 100(finished job), used when the actual event is under control. For the sake of brevity and usability, only the most common codes are in use for daily activities, and actual fire events require only a subset.

Typical code sequence for fire suppression starts with a fire notification "62", 2) followed by location confirmation and 3) a fire brigade dispatch notification towards "62" location, 4) Arrival at "62" location, 5) Status change to starting fire combat, 6) Status change when the situation is under control, 7) Once fire is suppressed andn the job finishes a "100" code is signaled and 8) further surveillance activities "84" are notified.

1.5 Cartographic information

Geographic information provides a common vocabulary of known places and organizational space. Information for the study area includes: administrative boundaries, urban sectors, access roads, watch towers, brigade camps, known localities and forest places, managed and protected areas, electrical and urban infrastructure, and water courses. In particular, a management grid or reticule comprising 1,047 action grid cells, each 100ha in, is used for joint coordination on fire tasks, including prevention, combat, and control activities, sanitization tasks, and environmental monitoring. In cartographic terms, each cell is 1km by 1km, encompassing large enough areas to support visualization and cartographic operations, as well as reports and administrative tasks.

After each fire event, a report is created with precise field measurements gathered afterwards, considering the location, extent, event type, affected area, and other relevant details.

Complementary information includes fire-affected areas, maintenance activities, areas under reforestation, animal and vegetation sightings, among other related topics. Reforestation activities, as integral parts of the fire management, are also supported by cartographic information, aligning affected areas, vegetation cover, including soil type, terrain aspect, orientation, water availability, and drainage, among others.

2. Materials and Methods

2.1 Connectivity and communication

Based on previous experience in the study area, barely 20-30% of transitable locations are reachable by two-way radios, so given the proximity to urban areas, cellular connectivity is considered and tested for establishing data communications. Given the heavy forest cover and steep geography, visibility gaps are still expected but given that the monitoring area is enclosed within a basin, connectivity is expected for most areas facing the city.

Under these conditions, MQTT (MQTT, 2014), an efficient publish/subscribe lightweight messaging protocol, is considered the basis for digital message exchange between the field devices and monitoring staff. It is regarded as an open, simple, and easy-to-implement protocol, making it ideal for situations with constrained environments where communication between machines and the Internet of Things(IoT) requires a small code footprint and has limited bandwidth.
Key characteristics include its one-to-many message distribution feature, a messaging transport independent of the payload characteristics. Additionally, multiple QoS (quality of service) levels are supported, enhancing message delivery and enabling clients to access published messages from a central repository.

MQTT has been tested for fire monitoring in industrial environments (Udurume et al, 2025), providing the technology to efficiently deliver messages with low latency between fire sensors and central monitoring. MQTT has also been tested for creating fire detection networks based on smoke, humidity, and temperature sensors, where messages received by the MQTT broker trigger further actions in case of alert (Kodali, 2018). Similarly, cases for urban environments (See and Ho, 2020) have paired IoT sensor data with GPS coordinates, raising alerts if fire conditions are detected. Alerts, based on location information, are sent to the nearest fire stations with context information attached, with the precise fire location and floor plans. Such studies show how a logical layer can enhance automatic fire response and provide enhanced context information to fire responders.
A similar fire detection solution, based on MQTT and IoT sensors, has been implemented in (Abdennabi, 2024), highlighting the broker's key role in efficient communication, real-time sensor monitoring and visualization, improving scalability, and enabling seamless interaction between devices, which in turn enables effective fire management.

MQTT-based communication has also been tested for emergency response and public safety alert systems in multiple urban scenarios, including fire (Zhang, 2025), where the need for rapid, automated detection and communication in emergency scenarios is crucial. Such systems, despite their urban setting, are considered scalable for use in rural or industrial environments. For each scenario, IoT devices provide real-time information to centralized platforms, which are considered key for enabling predictive and analytical solutions.

In terms of MQTT user count, a related work on agricultural usage is presented at (Turnip et al., 2023), reaching a maximum of 900 users under the proposed conditions. Such a system works not only with numerical sensor data but also with image data, relying on a central repository to provide monitoring resources.

So far, most work has been done on detecting fires using sensor data. Still, limited evidence is available on using MQTT for personnel monitoring in fire conditions with limited connectivity, so this case study evaluated the suitability of the delivery protocol for monitoring personnel location and receiving status updates, while displaying received data as geographical information in a spatial context with limited connectivity scenarios derived from a geographical context.

A special emphasis is made here not only on the message delivery or connectivity itself, but also on the expected increased volume of received information with shorter update intervals, employing automatic systems, and prioritizing personnel safety by reducing distractions to fire personnel.

2.2 Monitoring architecture

In this context, the MQTT broker requires all connected devices or clients to publish and consume messages from a central server at discrete moments, holding and routing messages to clients on demand and providing the most up-to-date information. In general terms, the proposed platform leaves to the clients the responsibility to either publish or consume information, while the server is only responsible for the message delivery on request. Field information is generated by users through their mobile devices and sent to the corresponding MQTT broker without requiring explicit user interaction. At the same time, fire managers retrieve field information in real-time from brigades and related assets, which is transformed into spatial records and visualized over a contextual map, providing instant situational information over current and recently known activities. Figure 2 depicts the information flow, originating at the field, retrieving location information, and sharing a status message, which is later consumed at the fire manager's office and visualized accordingly for decision making.
With a spatial picture, fire managers can take informed decisions based on location information and even make an educated guess when less information is received under limited communication conditions, enhancing situational awareness and enabling further asset management, which is not always possible with traditional two-way radios in the absence of line of sight.

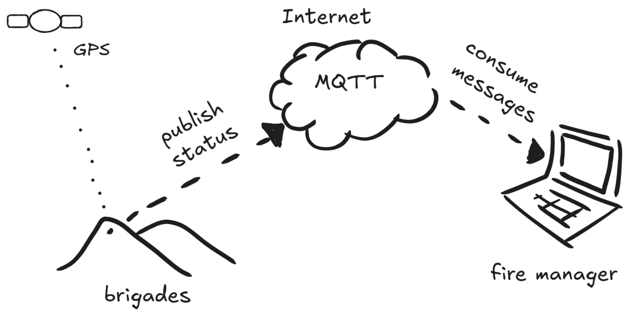

Figure 2. The proposed architecture is based on field clients gathering their current GNSS position and status, publishing messages to a central MQTT broker, and being consumed by the fire manager, who processes and visualizes information.

As fire managers collect and display assets using the web mapping platform, they apply various cartographic techniques to gain a deeper understanding, displaying status changes, brigade identification, and even temporal analysis when situations are time-dependent.
At the current stage, the system operates as a one-way system, publishing information for the office to consume. Still, information can also flow in different directions, from the manager's office to the fire brigades or even between fire brigades as required. Such additional communication paths are not considered yet, as they require an established action protocol and are left for future discussion.

2.2.1 Message structure: The considered model for tracking fire brigades integrates the following attributes within each message:
1) WGS84 GPS position: (latitude, longitude, height),
2) brigade status,
2) identification data.
4) timestamp.
Additional attributes and sensor information can be attached as required, such as temperature or CO2 levels, but these were not available, leaving only the fundamental information.

Messages sent to the MQTT broker are structured as topics and subtopics. The root topic is set as the protected area manager's name, followed by the brigade number, and further with individuals equipped with tracking devices when available. The following example illustrates the topic structure for firefighters, but is also applicable to vehicles fitted with tracking devices or even sensors when available.

<FireManager>/<Fire Brigade#>/<FireFighterA>

For the current study area, <FireManager> is the fire manager name <SDG>, standing for “Sierra De Guadalupe”. <FireBrigade> is the brigade’s nickname followed by its code number, i.e., “Encino5”. <FireFighter> is a brigade member or the brigade leader. The hierarchical schema allows filtering of the published messages without requiring extra processing code.

<SDG>/<Encino_1>/<Gabino>
<SDG>/<Encino_5>/<TransportA>

Filtering in the MQTT protocol can be done by subscribing to single topics or by using wildcards (#), so messages from multiple producers can be tracked down without prior knowledge of the available topics.

Different topic subscriptions can be portrayed using various cartographic techniques and spatial contexts. Received information is later logged and retrieved based on additional criteria such as a given date, status, brigade number, and even analyzed based on spatial relationships with respect to other spatial datasets. In general terms, this message structure allows for integrating different assets, either logical or physical, and tracking them during a fire event and even regular maintenance activities, as long as they have access to the communication network.

2.3 Monitoring Solution:

The current monitoring solution is implemented as two different MQTT clients. The first is a smartphone-based app for use in the field by the fire brigades, using their own existing cellphones and embedded location sensors and communication devices. During brigade activities, the app is running and pushes MQTT messages at regular intervals without intervention from the users. Personalization is limited only to changing the device identifier and the given name, as most actions occur automatically and need no user interaction.
The second is a web map application, subscribed to specific MQTT topics, processing the received messages over the administered area in real time. For every received message, location information is extracted and status displayed. If a different view about the carried activities is required, topic subscriptions can be modified to create alternative map content.

2.3.1 Mobile Platform: To monitor fire brigades in the field, a mobile client was developed with the MIT App Inventor platform (MIT App Inventor,2025), a single-map application providing a graphical overview of the current brigade position and an MQTT client to publish messages. It utilizes the location capabilities of modern smartphones to retrieve position information and its communication network to publish a formatted message. While running the mobile application, MQTT messages are sent at regular intervals without user intervention. Still, they can be forcefully sent per user request. Status changes are triggered by clicking on the specific status button. Most Frequent status messages have a dedicated button on the main screen. Figure 3 illustrates the mobile platform, designed as a single-page map application, with the user’s current location displayed with a marker centered on the map. The user can scroll around the map to gain context and use the provided buttons to change the current state.

Each message sends location information acquired by GNSS, a timestamp, brigade identifier, current status, and brigade name. Each device is uniquely identified within the MQTT broker, allowing simultaneous transmissions from different clients.

The monitoring workflow involves sharing information per fire brigade, including identification number, its current status at the beginning of activities and during status changes, time stamps, GNSS location, and elevation. This means every brigade should have a smartphone device, running the mobile app, and sending messages at regular intervals during their fire management activities. Each published message is delivered to all MQTT subscribers of a given topic.

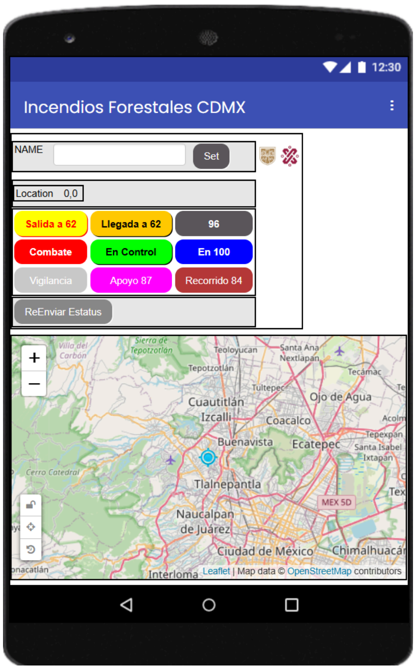

Figure 3: Mobile platform for sharing brigade’s information. Large buttons link to frequently used actions. The user’s current location is shown with a marker centered on the map.

2.3.2 Web Platform: Tracking and monitoring fire brigades is a key aspect of the system, achieved by subscribing to the proposed MQTT topics. By using wildcards (#), multiple topics can be filtered and fetched simultaneously without explicit knowledge of the publisher's topic. By processing received messages, real-time monitoring and visualization are possible for further decision-making activities.

Published MQTT messages containing brigade information are transformed into geospatial records, displaying location and status. Location is portrayed as a spatial feature by using a point representation, along with custom icons and status. Colors are expected to be in sync with the mobile platform schema, but it is not mandatory. If additional assets need to be tracked, extra icons and symbology can be considered as needed. Timestamps play an essential role in monitoring movements over time and logging daily records.

For management purposes, the described geographical information is made available and displayed for reporting, including grid information, administrative boundaries, access roads, and known locations. The implementation utilized the Mapbox GL JavaScript library (Mapbox, 2024) for mapping, offering both 2D and 3D views, map interaction, and styling features. The Mapbox platform (Mapbox, 2025) was used to serve background imagery, tiled geographic layers, and styling features for tiled information. In some cases, large spatial layers were provided without titles and served locally due to the size restrictions imposed by the mapping platform. The application was implemented as a NodeJS application using the Koa.js (KOA, 2025), which is a compact, minimalistic framework to create web applications and APIs. The final web application was deployed using a public web server and the MQTT server hosted in an external provider (HiveMQ, 2025), making it reachable to any device with Internet connectivity.

The mapping platform was configured to provide 3D views of the terrain and classical interactive map controls. The application allows querying per feature information using the pointing device and has control over the layers' visibility.

Figure 4 shows the web-based client where the tracked assets are displayed and updated in real time on top of spatial information related to fire management. Once a new message is received, a notification is shown to the user, and the marker position and status symbol are changed, so only the latest position and status are displayed without leaving trails.

In general terms, the information received is logged and stored as spatial records, where it can be retrieved and further analyzed based on a given date, status, or brigade number.

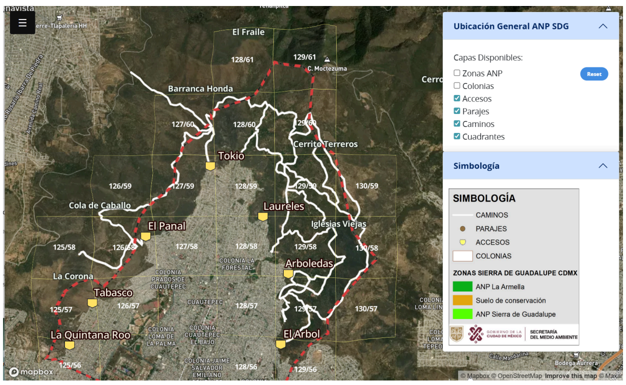

Figure 4. Web application based on a Mapbox mapping library and an MQTT client. Tracked information is overlaid on top of the map.

3. Results and Discussion

The lack of previous tracking efforts for the study area required setting a performance benchmark for the existing communication and monitoring capabilities with two-way radio communications. Estimations are based on the brigade's shared field experience, so the involved personnel were questioned about the following topics, and their responses were compared against the MQTT monitoring results. The considered performance metrics are 1) Brigades Location, 2) Brigades identification and status, 3) Update frequency, and 4) Communication reach.

3.1 Brigades Location

Without precise tracking, location information is limited to the last known place communicated by the brigades, which can be an educated guess based on available evidence, experience, or, if available, a named place. Such coarse information only provides rough estimations of the actual brigade's location and must be verified later against available maps and transformed into a grid system as described previously. In general terms, without precise coordinates, location is best estimated as one of the mentioned known places adjacent to the closest road.

With precise tracking provided by smartphones, position is acquired within GNSS precision rates expected under heavy forest coverage, with typical errors ranging from 5 to 10 meters. Here, the positional requirements for precision are set low, in the range of meters, but in contrast, the availability of location information under harsh conditions proves to be more critical. Of course, if favourable conditions exist, GNSS provides finer results. In this regard, the obtained GNSS precision is several orders of magnitude better (metric) than the described grid resolution.

3.2 Brigades Status

With two-way radio communications, a strict Line of Sight is required for proper communication, and clear transmissions are expected. Voice communications tend to be long, and signal disruptions impede adequate communication. When conditions exist, two possible message types occur: 1) non-situational events and 2) emergency events. The latter applies to fire outbreaks and begins with a sighting notification directed towards the radio base at the command center, followed by confirmation and dispatch. As resources are allocated, a coordinated dispatch takes relevance as more than a single event could occur on any given day at entirely different locations during fire season. Not all events require the same amount of tools and equipment, so according to the available evidence, estimated location, transportation means, and human resources, different dispatch decisions are taken.

At this stage, most communication efforts are effectively achieved between different radio bases and brigades, but not without issues. During dispatching, situational changes are transmitted using radio codes and updated at the command center.

After a dispatch event, status updates are not frequent due to the limited radio reach and the burden of actual tasks. Updates often happen at places well-established by operators where radio communications are possible. Such spots are usually road access or close to them, where brigades must stop to open gates. Such breaks are the most suitable time slots for establishing communication while not being actively engaged in fire combat activities. Brigades prioritize fire combat activities over active communication tasks.

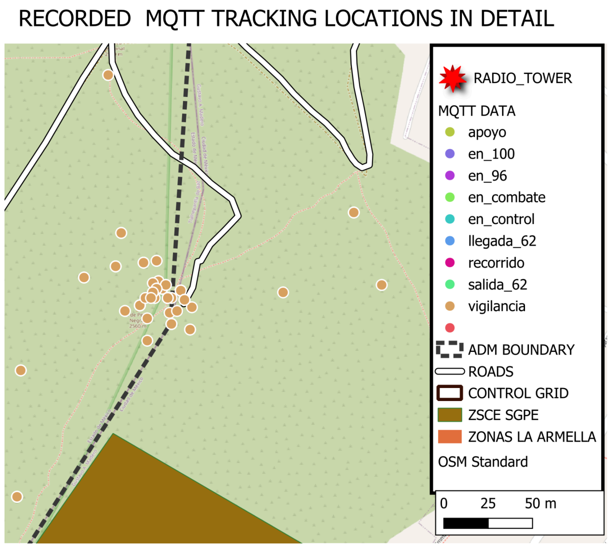

Figure 5. A close-up of the received information shows a brigade spreading after suppressing a fire outbreak, looking for remaining hot spots to cool them.

By using automated mapping and tracking devices, brigade status and location are transmitted at regular intervals. Status changes are automatically received by the MQTT broker and buffered for all its subscribers. In case of a status change, a message is sent by the user and visualized accordingly. In case of transmission errors, messages are simply discarded, and newer sent messages supersede older ones without user interaction so that users can complete their tasks without active disruptions. Figure 5 shows a map generated with the logged messages after a fire outbreak, where surveillance and ground cooling are being performed. Due to the automatic nature of the platform, no user intervention is required to publish or receive information, which differs from the classical two-way radio operations.

3.3 Update Frequency

Communication is affected by several aspects involving the sender, the medium, and the receiver. Brigades or senders usually lack the opportunity to communicate at regular intervals, as they are devoted to their tasks. If an opportunity arises, the medium or a proper line of sight is the next most relevant aspect for effective communication. If events unfold as expected, radio bases remain the most reliable link, as they have constant energy sources, more sensitive radio devices, and permanent personnel monitoring messages and keeping written records.

Under such assumptions, radio updates usually occur before and during the dispatch event. To a lesser extent, updates happen at the arrival and the start of fire combat. At the end of the event, communications increase as brigades are relieved of critical tasks and allowed to reach areas with communication. In such scenarios, updates occur in limited numbers and under strict situations for short periods. However, per protocol (SEDEMA, 2019), updates should occur every hour.

For the automated system, the MQTT protocol introduces a broker between users publishing messages and consumers, reducing human intervention. As the mobile system sends messages at regular intervals, it frees users from the need for active messaging. If a specific status change is required, it allows them to publish status changes on demand. Received messages are automatically stored in digital records, with minimal interaction required from the user in the office. Received information is updated as soon as it is received and overlaid on the screen in real time. Field and office users are relieved from active listening and free to perform other activities. Updates, sent at regular intervals, help to ensure compliance with the fire suppression protocol, which should be performed every hour.

The availability of multiple cellular networks from different carriers, combined with the variety of mobile devices, increases the success rate of messages sent. By default, messages are sent in regular five-minute intervals, fulfilling the expected protocol requirement of hourly updates. Frequent updates are not a strict requirement as brigades moving at slow paces have little positional changes and transports usually move at slow speeds too due to accidented roads, but with an increased number of sent messages, the probability of successful communications increases. Figure 5 shows trails of logged tracking information as points where brigades were moving between different locations, either for fire suppression activities or management activities. In all cases, the update rates allow for timely updates and estimate traffic conditions during the personnel movement to the fire outbreaks.

3.4 Communication reach

Radio communications are best performed when a clear line of sight exists or minor obstructions exist between emitters and receivers. Scattering surfaces also help to reflect signals, but are uncommon. Without radio repeaters, it is hard to achieve long-range communications in complex terrain.

For the study area, a central transmission tower exists, but it cannot fully cover the entire managed area. It is estimated to have a 20% to 30 % coverage, but only roads are considered the usable spots for communication, reducing the coverage numbers due to practical reasons to 10%..

The monitoring application relies on Internet connectivity provided by cellular communications, so the supporting cellular network, the transmission patterns of cellular towers, and the vertical transmission swat play a key role. Cellphone towers usually can cover vast areas at long distances at the expense of the vertical dispersion and transmission power, allowing transmissions only at relatively low vertical angles, typically between 10 and 20 degrees or less. With such numbers, the closer to the tower, the smaller the vertical reach, and the farther from the antenna, a broader vertical coverage can be achieved at the expense of the transmission power.
Given the proximity to urban areas, the coverage of cellular networks is greater than the existing radio coverage, with added services like data transmission and internet connectivity.
In broad terms, greater coverage is achieved with more than 40-60% rates, mainly due to the extensive cellular towers and different network carriers close to the study area. The added coverage allows not only tracking assets in fire situations but also supports regular management activities without disturbing actions such as reforestation activities and general maintenance.

Figure 6 shows the estimated radio coverage for the managed areas based on the operator's experience in the field. Green regions are estimated to have radio coverage, while white areas have little to no reach. When comparing the monitoring solution, the reach of the cellular network extends beyond existing radio coverage, depicted as points showing the brigades' position. When comparing the grid with the received locations, more grid cells are covered by the cellular network solution than by the two-way radio solution.

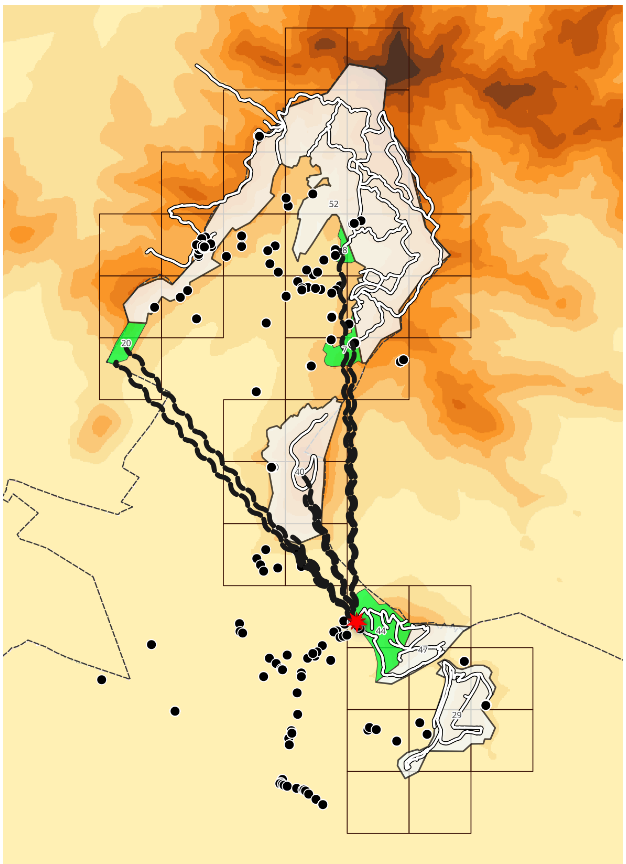

Figure 6. The protected areas are depicted as polygons under the management grid. Green polygons have radio reach, while white polygons do not. Curvy lines simulate the line of sight emanating from the transmission tower in red to places with known reach. Black points correspond to MQTT tracking information under cellular coverage.

4. Conclusions and future work

In broad terms, the use of cellular networks for communication, along with Internet access, was feasible given the study area's geographical characteristics, thereby increasing communication coverage. With increasing connectivity, the use of the MQTT protocol for regular message delivery enabled information exchange and the brigade's monitoring. MQTT proved to be a reliable message exchange mechanism with reliable delivery capabilities, providing the most recent field situation about fire brigades. The features requested, location and status updates per brigade, are successfully communicated with the fire managers, with the bonus of frequent updates and additional coverage versus typical two-way radio communications.

The availability of a mobile platform for communicating individual state changes and a monitoring website for collecting information provides additional tools for fire managers, turning brigades into visible tracking assets.

The platform, made with a distinctive focus on personnel tracking, differs from related MQTT implementations involving only fire detection or sensor data collection. Such a distinction helps protect the most valuable asset from the fire management perspective: human lives.

The monitoring platform, built around a map interface and the MQTT protocol, helps consolidate information about the brigade's latest location and status without distracting users while increasing situational awareness during different fire management activities. The improvements, in contrast with two-way radio communications, are the availability of location information, brigade's status information received at regular intervals and at higher frequencies while spanning larger areas.

Despite the increased connectivity, vast areas still lack cellular coverage, especially in regions with heavy forest cover and significant topographic obstacles. With the advent of newer off-the-grid communication technologies (Meshtastic, 2025), communication coverage can be increased when off-grid conditions arise and is under consideration for future development. The inclusion of additional sensor data, such as thermal and optical cameras, smoke, and gas readings, is also considered for future inclusion as MQTT is not tied to specific hardware or software, so that new devices can be integrated, and new clients created based on newer requirements when new technologies appear.

In conclusion, the described monitoring approach offers benefits to fire suppression activities when compared with the existing use of two-way radio communications only, enhancing personnel safety, increasing situational awareness, enabling asset tracking, and providing contextual information by means of spatial knowledge.

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