JURITEK: Jurnal Ilmiah Teknik Mesin, Elektro dan Komputer

E-ISSN: 2809-0799
P-ISSN: 2809-0802

Performance Evaluation of a Radio-Based Emergency Communication System for Mountain Hiking Applications

Elsa Anggraini[1*], Togi Simarmata[2], Mohammad Rayesa[3], Muhammad Fikri[4], dan Muhammad Fatih[5]

[1] Study Program Electrical Engineering, University of Jambi; email : elsalolitaanggraini@unja.ac.id
[2] Study Program Electrical Engineering, University of Jambi; email : togisiholmaritosimarmata@unja.ac.id
[3] Study Program Electrical Engineering, University of Jambi; email : m.alfizarayesa@unja.ac.id
[4] Study Program Electrical Engineering, University of Jambi; email : muhammadkhalis@unja.ac.id
[5] Study Program Information System, University of Jambi; email : muhammaddamasfatih@unja.ac.id
*** Corresponding Author** : Elsa Anggraini

Abstract: Reliable communication is essential for mountain hiking activities, particularly in emergency situations where cellular networks are often unavailable. This study evaluates the performance of a radio-based emergency communication system designed to transmit GPS location data from multiple transmitter nodes to a single receiver using a multipoint-to-point communication scheme. The main contribution of this work is the field-based evaluation of a practical communication system capable of delivering location information from multiple users in mountainous environments without relying on cellular infrastructure. Field experiments were conducted using handheld radios operating in the 400–470 MHz frequency band under both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions. The results show that the system achieved maximum communication distances of 834.40 m and 648.03 m under LOS conditions, while NLOS communication was maintained up to 279.00 m and 277.18 m. In addition, the transmitted GPS coordinates were successfully received and displayed at the monitoring station with positional differences of only a few meters compared to a reference GPS application. These results demonstrate that the proposed system can provide a practical and reliable solution for emergency communication and location monitoring in mountainous environments.

Keywords: Multipoint to Point; Radio Communication; CSMA; Mountain Hiking; Emergency Communication

Abstrak: Komunikasi yang andal sangat penting dalam aktivitas pendakian gunung, terutama pada situasi darurat ketika jaringan seluler sering kali tidak tersedia. Penelitian ini mengevaluasi kinerja suatu sistem komunikasi darurat berbasis radio yang dirancang untuk mengirimkan data lokasi GPS dari beberapa node pemancar ke satu penerima menggunakan skema komunikasi *multipoint-to-point*. Kontribusi utama penelitian ini adalah evaluasi berbasis pengujian lapangan terhadap sistem komunikasi praktis yang mampu menyampaikan informasi lokasi dari beberapa pengguna di lingkungan pegunungan tanpa bergantung pada infrastruktur seluler. Pengujian lapangan dilakukan menggunakan perangkat *Handy Talky* yang beroperasi pada rentang frekuensi 400–470 MHz dalam kondisi *line-of-sight* (LOS) dan *non-line-of-sight* (NLOS). Hasil pengujian menunjukkan bahwa sistem mampu mencapai jarak komunikasi maksimum sebesar 834,40 m dan 648,03 m pada kondisi LOS, serta mempertahankan komunikasi hingga 279,00 m dan 277,18 m pada kondisi NLOS. Selain itu, data koordinat GPS yang dikirimkan berhasil diterima dan ditampilkan pada stasiun pemantauan dengan selisih posisi hanya beberapa meter dibandingkan dengan aplikasi referensi GPS. Hasil ini menunjukkan bahwa sistem yang diusulkan dapat menjadi solusi yang praktis dan andal untuk komunikasi darurat serta pemantauan lokasi secara *real-time* di lingkungan pegunungan.

Kata kunci: Multipoint to Point; Komunikasi Radio; CSMA; Pendakian Gunung; Komunikasi Darurat

Diterima: June 18, 2026
Direvisi: July 12, 2026
Diterima: July 17, 2026
Diterbitkan: July 15, 2026
Versi sekarang: July 30, 2026

1. Introduction

During emergency situations, effective coordination between affected individuals and response teams is essential to reduce the risk of injuries and fatalities. Reliable communication plays a critical role in enabling such coordination. However, conventional communication infrastructures such as cellular networks may become unavailable, congested, or damaged during disasters or in remote environments. Consequently, alternative communication solutions are required to maintain connectivity when traditional infrastructure is degraded or unavailable. Emergency communication systems are therefore designed to operate under such constraints, providing a means for transmitting essential information when standard networks fail or become overloaded [1],[2].

2. Literature Review

2.1. Emergency Communication

Emergency communication networks are commonly used in various scenarios where rapid information exchange is critical for safety and coordination, including natural disasters, rescue operations, and remote field activities. To ensure adaptability and reliability, these systems often incorporate multiple technologies such as cellular networks, satellite communication, private wireless networks, and ad hoc wireless systems [3],[4]. While these technologies provide robust communication capabilities, many of them depend on sophisticated infrastructure or specialized equipment that may not be readily available in remote environments such as mountainous regions [5].

In such situations, direct radio communication offers a practical alternative to infrastructure-dependent systems. Radio-based communication can operate independently of centralized networks and enable direct peer-to-peer information exchange, making it particularly suitable for emergency scenarios in remote areas. As a result, radio communication systems have been widely deployed in various emergency applications due to their simplicity, portability, and ability to provide basic voice or data transmission in challenging environments [6], [7].

2.2 Hiking Environment

Despite these advantages, the performance of radio-based communication systems can be significantly influenced by environmental conditions. Mountain hiking environments present unique challenges for wireless communication due to terrain variations, obstructed line-of-sight (LOS), and limited cellular coverage. These factors can affect signal propagation and communication reliability, causing system performance to differ considerably from results obtained in controlled or urban environments [8]. Therefore, field-based evaluations are necessary to assess how key communication parameters—such as effective transmission range and successful data reception—are affected by real-world topographical conditions [9].

Although several studies have investigated emergency communication technologies, most of them focus on infrastructure-based systems or conduct evaluations in controlled environments. There remains a lack of field-based studies that specifically examine the performance of radio-based emergency communication systems in challenging outdoor environments such as mountain hiking locations. In particular, limited research has evaluated practical system-level performance metrics, including effective communication range, reliability of location data transmission, and the capability to support multiple transmitters in a real-world emergency communication scenario.

To address this research gap, this study presents a field-based performance evaluation of a radio-based emergency communication system designed for mountain hiking applications. Unlike previous studies that primarily focus on conceptual system designs or laboratory-based testing, this research evaluates the system under real outdoor conditions, with emphasis on practical communication performance metrics such as successful reception of location information, effective communication distance, and the ability to handle multiple transmitters in a multipoint-to-point configuration.

The main contributions of this study are summarized as follows:

a. Conducting a real-world field evaluation of a radio-based emergency communication system in a mountain hiking environment.

b. Analyzing key communication performance metrics, including effective communication range and successful reception of location data under varying topographical conditions.
c. Evaluating the system's capability to support multiple transmitters in a multipoint-to-point emergency communication scenario.
d. Providing practical insights into the feasibility of radio-based communication systems for emergency applications in remote outdoor environments

3. Methodology

Given the need to assess the effectiveness of a radio-based emergency communication system for mountain climbing applications, this study uses a field-based experimental technique. Instead of using simulations or laboratory-based testing, the methodology focuses on evaluating system behavior in actual environmental settings.

3.1. System Overview

The evaluated emergency communication system, as shown in Fig. 1, is appropriate for distant outdoor settings like mountainous hiking locations because it is made to operate independently of traditional cellular or infrastructure-based networks. The transmitter nodes are the starting point of the system's data collecting and transmission sequence, which ends at a centralized monitoring receiver [10],[11].

Each node on the transmitter side first collects geographic location data from a GPS module. GPS data provides latitude and longitude information, which indicate the hiker's present location. These location data allow the monitoring device to pinpoint the exact location of each transmitter node in the field, which is critical for emergency response. Radio communication for location reporting has been shown to be an effective component of emergency systems in situations where conventional infrastructure is unstable or unavailable [12].

The transmitter unit integrates a GPS module (Ublox Neo-6M), an Arduino Nano microcontroller, an AFSK modulator (TCM3105), and a handy talky radio device (SPC SH-10). The GPS module obtains the geographic coordinates of the hiker in the form of latitude and longitude. These coordinates are processed by the microcontroller and encoded into digital data frames before being modulated using the AFSK modem. The usage of VOX further aids the transmission mechanism by allowing automatic channel access when data is ready for transmission. Each transmitter node sends an audio signal to the VOX circuit, which allows the radio to transmit only when the channel is accessible. This technique reduces the need for manual intervention while also promoting orderly data transfer across several nodes.

The modulated signal is then transmitted via the handy talky radio using the UHF frequency band. The receiver unit consists of another handy talky radio connected to an AFSK demodulator and a microcontroller. The received signal is demodulated to retrieve the transmitted data and forwarded to a laptop via USB to TTL converter. The monitoring software displays the received coordinates on a digital map using the Google Maps interface.

The system is designed to support a multipoint-to-point communication architecture, allowing multiple transmitter nodes carried by hikers to send emergency messages to a single monitoring station.

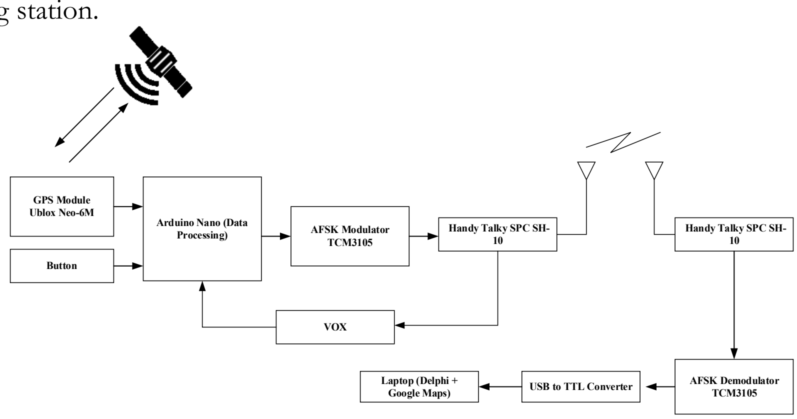

Figure 1. Transmitter and Receiver System

Following acquisition, the geographic data is formatted into a structured data packet appropriate for modulation before being transmitted over radio. Handheld radios are widely utilised in field operations because of their portability, simplicity, and independence from external infrastructure. This system's radio transceiver works in a frequency range that these kinds of devices can use. However, because numerous transmitters use the same communication channel, only one node can transmit at a time [13], [14], [15].

Transmission control methods are employed to regulate channel access and reduce interference among nodes. Such techniques are especially crucial in multipoint-to-point communication systems, where multiple transmitter nodes relay data to a singular recipient. Channel access control is crucial for ensuring dependable data transfer while reducing packet collisions and transmission delays [16]

The incoming radio signal is demodulated and decoded at the receiver to obtain the geographic coordinates that were transmitted. These coordinates are subsequently sent to a monitoring application, which displays the locations of the transmitter nodes on a digital map. Real-time visualisation of GPS-based position data improves situational awareness and allows for speedier decision-making during emergency response operations. Integrating location reporting with mapping interfaces has been widely used in emergency monitoring systems to promote efficient rescue coordination [17].

3.2. Experimental Environment

The field evaluation was conducted in a mountain hiking environment with varied terrain and varying elevation levels. The test location comprises woodland routes, open hiking trails, and topographical slopes that may partially block the line-of-sight (LOS) between the transmitter nodes and the base station.

Such environmental variables mirror true communication obstacles that mountain hikers face, such as signal attenuation induced by vegetation, topography elevation changes, and non-line-of-sight communication pathways. These conditions were chosen to assess the practical feasibility of the proposed radio-based emergency communication system in isolated outdoor settings with limited or no cellular access.

3.3. Multipoint-to-Point Communication System Architecture

In the multipoint-to-point communication structure shown in Figure 2, three transmitter nodes use a single radio channel to send emergency data to a single receiver. On the receiver side, the demodulated GPS signals are transferred to a Delphi-developed monitoring application. The software functions solely as a visualisation and data presentation interface, allowing for real-time monitoring and recording of received latitude and longitude data.

The system uses a CSMA-based channel access mechanism to regulate data delivery. Throughout operation, each transmitter node transmits data in a sequential manner. Before starting a broadcast, a transmitter uses carrier sensing to see if the channel is already filled by another node. If the channel is busy, the transmission process is temporarily paused [18].

It is important to highlight that this system does not use traditional collision detection because the handheld radio hardware cannot send and receive signals at the same time, making it impossible to detect signal overlap over the wireless medium. Instead, the technique uses carrier sensing to ensure that broadcasts from the three transmitter nodes are temporally separate, lowering the risk of packet collisions. As a result, data received at the receiver node are treated individually, ensuring that emergency alerts from many transmitters stay unique under normal working settings [19].

However, there are certain limitations to this protocol. While successful for a limited number of nodes, the probability of packet collisions may increase with increased node density or in the presence of the "hidden node" problem, which occurs when transmitters cannot detect each other's carriers. Nonetheless, the results demonstrate that this communication technique can reliably handle three transmitter nodes using a shared radio channel under the studied field conditions [20].

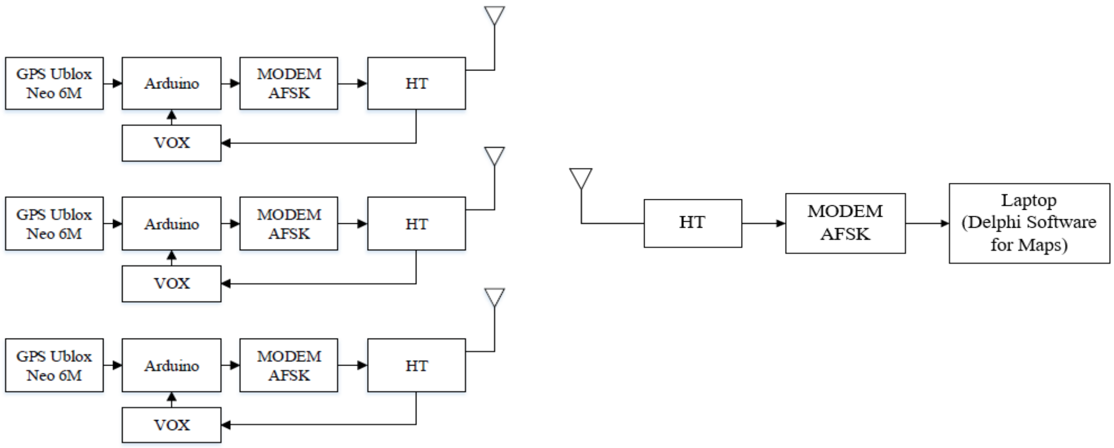

Figure 2. Multipoint to Point System

3.4. CSMA System Architecture

The system utilizes a CSMA access mechanism alongside a streamlined data frame format to provide organized data transmission across a shared radio channel. This method guarantees that data sent from several nodes can be accurately recognized and handled by the receiver without confusion [21].

Each transmitted data packet comprises three distinct frames, corresponding to the three transmitter nodes utilized in the system. Each frame comprises three fundamental fields: transmitter ID, latitude, and longitude. The transmitter ID functions as an identifier to differentiate the data source, and the latitude and longitude fields denote the geographic location acquired from the GPS module [22].

The transmitter identifiers are designated as 001, 002, and 003, denoting the three transmitter nodes involved in the communication process. By allocating distinct IDs to each transmitter, the receiver may distinguish incoming data frames and correlate the received position information with the appropriate transmitter node, as seen in Table 1.

Table 1. Data Frame Structure

Frame Order	Transmitter ID	Latitude	Longitude
Frame 1	001	Lat_1	Lon_1
Frame 2	002	Lat_2	Lon_2
Frame 3	003	Lat_3	Lon_3

Before transmitting a packet, each transmitting node performs carrier sensing to determine channel availability. The node commences frame transmission if the channel is detected to be idle. If a channel is occupied, transmission is delayed until it becomes available. This CSMA-based technique ensures that frames are sent sequentially rather than concurrently, reducing the likelihood of frame collisions. At the receiver's final point, incoming frames are processed sequentially. Due to the sequential nature of transmissions, the receiver is able to accurately decode each frame and retrieve the associated ID, latitude, and longitude data. Consequently, location data from various transmitter nodes remain distinct and do not intermingle during reception. The structured frame format, coupled with carrier-sensing access, enables the receiver to accurately read data from all three transmitters inside a common communication channel [23].

3.5. LOS and NLOS Environment System

Field experiments were performed to assess the efficacy of the proposed radio-based emergency communication system in authentic mountain trekking circumstances. The experimental configuration was established to emulate real-world deployment situations, when emergency data are relayed from various field nodes to a central receiver independent of cellular infrastructure.

The system was assessed utilizing three transmitter nodes and one reception node, functioning within the identical radio channel. Each transmitter node transmitted emergency data frames that included the transmitter ID, latitude, and longitude information, as outlined in the preceding subsection. Data transmissions were executed sequentially via a CSMA protocol to avert concurrent channel utilization.

Measurements were performed at different distances between the transmitter nodes and the receiver to examine the impact of communication range on data reception. Testing scenarios encompassed both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions, reflecting typical circumstances experienced in hilly terrains due to elevation and natural barriers. System performance was evaluated using practical and observable parameters, including:

- Effective communication distance refers to the maximum range at which emergency data frames can be successfully received.
- Successful acquisition of GPS location data, ascertained through the accurate decoding of latitude and longitude coordinates at the receiver.
- Assess frame reception consistency by determining the receiver's capability to accurately interpret data frames from all three transmitter nodes without data conflation.

These criteria were chosen to prioritize operational feasibility and dependability over low-level communication metrics. The experimental configuration emphasizes practical applicability and corresponds with the aim of assessing system performance in real-world situations

4. Experiment Result

This section delineates the experimental outcomes derived from the field assessment of the proposed radio-based emergency communication system. The results aim to illustrate the system's actual performance in a mountainous hiking setting, where communication circumstances are significantly affected by terrain features, line-of-sight accessibility, and environmental impediments.

The assessment concentrates on aspects that are directly observable from the experiments undertaken, including communication distance, reception of GPS-derived location data, and the system's behavior in a multipoint-to-point communication context. The selected parameters represent the fundamental necessities of an emergency communication system, namely dependable data transmission and precise position reporting in environments devoid of infrastructure.

The results presented in this section originate from several transmission trials executed under diverse distances and environmental conditions. The discourse underscores the correlation between communication range and signal reception, the reliability of received GPS data, and the efficacy of the CSMA protocol in facilitating orderly data flow from many transmitter nodes. The findings are examined to assess the appropriateness of the suggested method for emergency communication during mountain climbing activities.

4.1 . Communication Distance Performance

The communication range efficacy of the assessed emergency communication system was examined via field testing in both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. The aim of this study was to assess the effective transmission range of the radio-based system in a hilly setting utilizing handheld transceivers throughout the VHF/UHF frequency spectrum.

The experimental results indicated that the maximum communication lengths attained under line-of-sight conditions were 834.40 m and 648.03 m. The values demonstrate that the system may sustain sustained communication over considerable distances when an unobstructed propagation channel exists between the transmitter and receiver. Conversely, the communication distances in NLOS situations were markedly diminished, with recorded ranges of 279.00 m and 277.18 m, underscoring the substantial impact of topographical barriers on signal transmission.

The radio communication system functions within the 450–457 MHz frequency band, typically utilized by handheld transceivers for short- to medium-range communication. In this frequency range, radio wave propagation is moderately influenced by diffraction and blockage, especially in uneven terrains like hilly regions. Basic radio propagation theory posits that the communication distance is affected by elements such as operating frequency, antenna elevation, transmission power, and climatic conditions. Lower frequencies typically offer enhanced penetration and diffraction capacities; yet, physical barriers still cause significant signal attenuation in non-line-of-sight conditions.

The empirically derived communication distances were subsequently compared with the theoretical free-space propagation characteristics associated with the operating frequency spectrum. Although free-space models offer an optimal estimation under the assumption of unimpeded routes, empirical results reveal significant discrepancies attributable to actual environmental circumstances. The noted decrease in communication range under NLOS settings corresponds with anticipated propagation traits in mountainous regions, where hills, vegetation, and surface irregularities contribute to increased route loss.

The results show that the proposed system can establish reliable communication at distances more than several hundred meters under line-of-sight (LOS) conditions, while non-line-of-sight (NLOS) operation is possible within a much restricted range. As a preliminary field review, these findings highlight the importance of deployment planning and node location in emergency communication contexts, particularly in outdoor settings where LOS may not be guaranteed. It should be noted that, while the existing data gives a basic insight of the system's performance, the number of measurements was limited by the specific topography and environmental limits encountered during the field test.

The significant decrease in communication range under NLOS conditions—more than 50% compared to LOS—demonstrates the 400-470 MHz band's extreme susceptibility to physical barriers such as dense trees or rocky outcrops. This means that, in practical mountain rescue scenarios, the receiver node should be placed on higher land or clear slopes to maintain a strong communication with transmitters in valleys. Tables 2 and 3 show a summary of the assessed communication distances for both LOS and NLOS scenarios.

Table 2. Communication Distance under Line-of-Sight (LOS) Conditions

Test Scenario	Measured Communication Distance (m)
Test 1	834.40
Test 2	648.03

Table 3. Communication Distance under Non-Line-of-Sight (NLOS) Conditions

Test Scenario	Measured Communication Distance (m)
Test 1	279.00
Test 2	277.18

Tables 3 and 4 display the measured communication distances acquired under Line of Sight (LOS) and Non-Line of Sight (NLOS) situations, respectively. A significant decrease in attainable communication range occurs under NLOS settings due to topographical blockage and signal attenuation

The discerned disparity between LOS and NLOS communication ranges validates the substantial influence of topographical obstructions on radio-based emergency communication systems. These findings emphasize the necessity of accounting for environmental circumstances while implementing multipoint-to-point radio systems in hilly regions, especially for emergency applications where dependable communication is essential.

4.2. GPS Location Data Reception

This paragraph describes the results of GPS coordinate reception obtained through the proposed emergency communication system. The monitoring program's (Delphi 7.0) latitude and longitude values were compared to the coordinates provided by the MyGPS application as a benchmark. The MyGPS program was chosen as a reference because of its demonstrated capacity to provide high-precision NMEA-based data on commercial mobile devices, giving it a useful baseline for field-scale comparisons [24]

The comparison was carried out during three independent measurement intervals—morning, afternoon, and evening—to test the consistency of the collected GPS data under different temporal conditions. Coordinate discrepancies were converted to linear distance using the Spherical Earth Model approximation. In this study, the Earth is approximated as a sphere with a mean equatorial circumference of around 40,075 km. The circumference divides one degree (1°) into 60 arc-minutes (1') and 3,600 arc-seconds (1"). A positional difference (Δ) of one arc-second (1") is equivalent to a physical distance of roughly 30.92 meters [25]. The linear error was computed by calculating the absolute difference (Δ) in arc-seconds between the monitoring program ($\mathsf{Coord}_{\mathsf{sys}}$) and the reference application ($\mathsf{Coord}_{\mathsf{ref}}$), using the following equation (1):

$$Distance\ Error\ (m)\ =\ |Coord_{sys} - Coord_{ref}|\ \times\ 30.92 \tag{1}$$

Spherical models are essential in map projection and geodetic computations for specific locations. While the Earth's shape is more accurately represented as an ellipsoid [26] suggest that a spherical approximation is sufficient robust and mathematically efficient for short-range distance evaluations—specifically for distances under 1 km—where the deviation from more complex ellipsoidal models remains negligible. To determine the acceptability of this inaccuracy for emergency and Search and Rescue (SAR) operations, it is critical to consider operating standards in remote situations. According to[27] , consumer-grade GNSS units typically have accuracies ranging from 1 to 5 m in open circumstances, which can rise to 3.8 to 12 m beneath mature forest canopies. Furthermore, the study emphasises that the fundamental requirement for mission-critical safety and health applications, such as identifying first responders or victims in off-grid areas, is the capacity to exchange real-time position information independent of cellular infrastructure. The obtained error in this system remains considerably below the 12-meter threshold commonly observed in dense forests, making it extremely acceptable for SAR applications. This level of precision, combined with the radio-based multipoint-to-point communication system, enables that rescue teams can be directed to a specific search area where visual or auditory contact can be established.

A comparison of GPS coordinate reception throughout the morning, afternoon, and evening measurement periods is provided to highlight the proposed system's reliability under changing temporal conditions. The comparison is based on the mean spatial differences between the GPS coordinates received by the monitoring software and those displayed by the MyGPS reference application.

The results show that the afternoon measurement interval is the most consistent, with mean spatial variations of 0.029 m for latitude and 0.14 m for longitude. The morning and evening measurements show larger average disparities, with both periods having comparable average values of approximately 3.97 m for latitude and 4.85 m for longitude. Despite these disparities, the measured deviations remain within a few meters at all measurement intervals. The higher consistency observed in the afternoon is the result of improved satellite geometry and signal reception conditions, which normally occur when a larger number of satellites are accessible and uniformly distributed. Meanwhile, the increased fluctuations in the morning and evening may be influenced by changes in satellite visibility and environmental conditions.

These findings are comparable with those from prior studies on GPS accuracy in IoT-based tracking systems. For example, investigations using identical low-cost GPS modules in outdoor situations found positional inaccuracies ranging from 2 m to 10 m under regular open-sky conditions, which corresponds to the morning and evening variations seen in the current study. Furthermore, the sub-meter accuracy reached during afternoon measurements is equivalent to those reported in GPS-based vehicle and personnel tracking systems, where favourable satellite geometry boosts positional precision greatly. This shows that the suggested system's accuracy performance is comparable to existing GPS-enabled monitoring solutions in similar environmental conditions [28], [29], [30].

Practically speaking, these findings have important implications for real-world emergency communication circumstances. In most emergency response circumstances, location precision of a few meters is adequate to determine the approximate site of a distress signal, allowing first responders to get to the correct place efficiently. The sub-meter accuracy recorded during afternoon times strengthens the system's potential to provide high-precision location reporting when satellite circumstances are ideal. Even in the morning and evening, when deviations approach 4-5 m, the system remains operationally feasible, since emergency coordinators can still determine a responder's or victim's position with an appropriate margin.

This level of precision enables time-critical decision-making in disaster relief, search-and-rescue, and remote area monitoring scenarios [31] [32].

The proposed system has numerous major advantages. First, it maintains consistent GPS reception across time without requiring extra correction infrastructure such as Differential GPS (DGPS) or Real-Time Kinematic (RTK) systems, making it cost-effective and deployable in resource-constrained contexts. Second, the system's consistent performance across different temporal contexts demonstrates its suitability for continuous monitoring applications. However, certain restrictions must be recognised. The reduction in accuracy found during the morning and evening periods suggests a reliance on satellite geometry, which is fundamentally changing and outside the system's control. Furthermore, the current evaluation was conducted under open-sky settings; performance in urban canyons, dense woodlands, or interior environs – scenarios common in real-world emergencies — may result in higher positioning inaccuracies. Future research should address these limitations by investigating the integration of complementary positioning technologies, such as Wi-Fi-based localisation or inertial navigation systems, to increase accuracy in tough environments [33], [34], [35].

The comparative results show that the proposed emergency communication system can reliably receive and transmit GPS-based location information at different times of day. Figure 5 shows a graphical comparison of the average regional differences for each measurement period, providing a visual representation of the discovered trends.

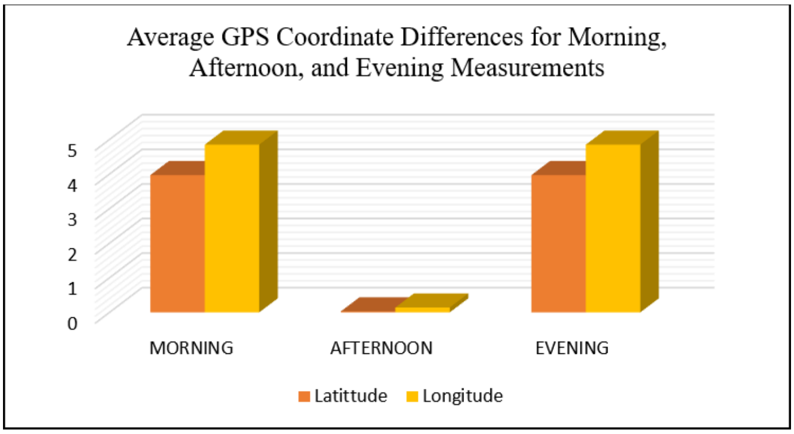

Figure 3. Comparison of Average GPS Coordinate Differences Across Different Measurement Periods

4.3. GPS Location Data Reception

This subsection examines the functionality of the proposed emergency communication system inside a multipoint-to-point communication framework. The assessment centers on the capacity of numerous transmitter nodes to broadcast data in succession to a singular receiver node without incurring data collisions.

Three transmitter nodes were planted and configured to relay emergency data to one receiver in the conducted experiments. Each transmitter was allocated a distinct identifier: ID 001, ID 002, and ID 003, which was integrated into the data frame. The identifiers enable the recipient to differentiate the origin of each incoming data packet.

The transmission process is governed by a CSMA channel access mechanism, wherein each transmitter assesses the channel prior to commencing transmission. When the channel is identified as unoccupied, a transmitter is permitted to transmit its data packet. Should the channel be occupied by an active transmission from another node, the transmitter defers its transmission and remains in a state of readiness until the channel is accessible. This method allows the transmitter nodes to function alternately, so averting concurrent broadcasts.

The testing findings indicate that the data packets sent from ID 001, ID 002, and ID 003 were successfully received and decoded by the recipient node. The monitoring application presents the incoming data in real time, with each identifier distinctly recognized and sequentially shown. No overlapping or mixed data were detected during the monitoring phase, signifying that the transmitted frames were accurately delineated at the receiver.

The lack of data collisions in the observed transmissions validates the efficacy of the implemented CSMA-based access mechanism in facilitating orderly communication among many transmitter nodes. By permitting only a single node to transmit at any given moment, the system guarantees dependable data delivery and averts frame corruption at the receiver. The results indicate that the proposed multipoint-to-point communication technique is appropriate for emergency communication situations when numerous users send location data to a central monitoring unit.

The successful reception of the sent GPS coordinates is additionally verified through eye observation at the receiver's end. Fig. 5 illustrates that the geographic coordinates associated with the received data frames are accurately shown on the map interface, demonstrating that the latitude and longitude data relayed by the transmitter nodes is precisely decoded and depicted.

The output of the monitoring program depicted in Fig. 6 indicates that the received data frames are displayed in real time, with each incoming packet distinctly linked to its respective identifier (ID 001, ID 002, and ID 003). The sequential display of IDs in the monitoring interface indicates that the data are received alternately, without overlap or intermingling. These observations further substantiate the efficacy of the multipoint-to-point communication method and the implemented CSMA access mechanism in facilitating orderly data transmission.

5. Conclusion

This study evaluated a radio-based emergency communication system for mountain hiking applications using a multipoint-to-point communication framework. Field tests show that the system reliably sends GPS-based location data from three transmitter nodes to a single receiver without data collisions using a CSMA-based protocol. Communication experiments in the 400-470 MHz band yielded maximum ranges of 834.40 m and 648.03 m under LOS conditions, and 279.00 m and 277.18 m under NLOS conditions, which are consistent with expected propagation behaviour. GPS coordinates were correctly decoded at the monitoring station, with positional differences of only a few meters when compared to a reference application, showing appropriate precision for emergency location reporting. These findings validate the system as a feasible, infrastructure-independent alternative for emergency communication and real-time position tracking in high terrain.

Despite these contributions, the study has a number of drawbacks. The evaluation used only three transmitter nodes in specified climatic conditions, and the single-hop architecture limits operational range in difficult terrain. GPS accuracy was confirmed against a commercial reference application rather than a high-precision ground truth system, and the system's performance under poor weather circumstances has yet to be tested.

Future work should investigate multi-hop relay and repeater integration to extend coverage in deep NLOS scenarios, as well as scalability testing of the CSMA protocol at larger node density. Integration with SAR coordination platforms and GIS mapping tools is advocated for increased operational value. Furthermore, adding physiological sensors into transmitter nodes, testing other frequency bands like LoRa, and performing long-term field experiments with SAR professionals would help to validate and improve the system's real-world applicability.

Author Contributions: Conceptualization: Elsa and Togi; Methodology: Elsa; Software: Fikri & Fatih; Validation: Elsa &Togi; Formal analysis: Elsa; Investigation: Khalis; Resources: Fatih; Data curation: Rayesa; Writing original draft preparation: Elsa; Writing review and editing: Elsa; Visualization: Fatih & Rayesa; Supervision: Elsa;

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors would like to thank Togi, Rayesa, Fikri, and Fatih for providing administrative and technical support during this research.

Conflicts of Interest: The authors declare no conflict of interest.

Referensi

[1] A. Carreras-Coch, J. Navarro, C. Sans, and A. Zaballos, "Communication Technologies in Emergency Situations," Apr. 01, 2022, *MDPI*. doi: 10.3390/electronics11071155.

[2] Q. Wang *et al.*, "An Overview of Emergency Communication Networks," Mar. 01, 2023, *MDPI*. doi: 10.3390/rs15061595.

[3] F. Kagai, P. Branch, J. But, R. Allen, and M. Rice, "Rapidly Deployable Satellite-Based Emergency Communications Infrastructure," 2024, *Institute of Electrical and Electronics Engineers Inc.* doi: 10.1109/ACCESS.2024.3465512.

[4] H. Song and J. M. Chung, "Next-generation wireless communication technologies for improved disaster response and management," *ETRI Journal*, vol. 47, no. 3, pp. 375–392, Jun. 2025, doi: 10.4218/etrij.2024-0546.

[5] Priyangshu Sutradhar, "Drone-Assisted Mesh Networks: A Framework for Emergency Connectivity in Remote and Low-Infrastructure Zones," *International Journal of Advanced Research in Science, Communication and Technology*, pp. 113–119, May 2025, doi: 10.48175/ijarsct-27018.

[6] K. Prasad, S. Vandhana, G. Sudharshan, A. Srinivasulu, and M. M. Varma, "Development OF a Portable Emergency Ham Radio Communication System For Disaster Response," in *2025 International Conference on Computer, Electrical & Communication Engineering (ICCECE)*, 2025, pp. 1–7. doi: 10.1109/ICCECE61355.2025.10940426.

[7] A. Qaddus and A. A. Minhas, "Spreading Seamless Radio over IP Services in Tactical Public Safety Communications using PTP Microwave IP Radio Networks," in *2022 39th National Radio Science Conference (NRSC)*, 2022, pp. 233–240. doi: 10.1109/NRSC57219.2022.9971372.

[8] T. Jawhly, "Analysis of the fresnel breakdown and diffraction losses across a hilly terrain region," *Discover Electronics*, vol. 2, no. 1, May 2025, doi: 10.1007/s44291-025-00075-w.

[9] A. Booranawong, P. Hirunkitrangsri, D. Buranapanichkit, C. Pochaiya, N. Jindapetch, and H. Saito, "A 2.4 GHz IEEE 802.15.4 Multi-Hop Network for Mountainous Forest and Watercourse Environments: Sensor Node Deployment and Performance Evaluation," *Signals*, vol. 5, no. 4, pp. 774–793, Dec. 2024, doi: 10.3390/signals5040043.

[10] L. Sciullo, A. Trotta, and M. Di Felice, "Design and performance evaluation of a LoRa-based mobile emergency management system (LOCATE)," *Ad Hoc Networks*, vol. 96, p. 101993, 2020, doi: https://doi.org/10.1016/j.adhoc.2019.101993.

[11] B. Alorda-Ladaria, M. Pons, and E. Isern, "A Self-Configurable BUS Network Topology Based on LoRa Nodes for the Transmission of Data and Alarm Messages in Power Line-Monitoring Systems," *Sensors*, vol. 25, no. 5, Mar. 2025, doi: 10.3390/s25051484.

[12] S. O. Un, K. Po, K. Thourn, R. Pec, C. Srun, and S. Siren, "Design of Emergency Position Reporting System for Disasters Using Amateur Radio and Automatic Packet Reporting System (APRS) as a Mobile Station Operator for Educational Purposes," *Indonesian Journal of Educational Research and Technology*, vol. 3, no. 3, pp. 257–264, Aug. 2022, doi: 10.17509/ijert.v3i3.58888.

[13] M. Hermann and B. Bloessl, "On the Feasibility of Digital VHF Communications in Crisis Scenarios," in *2024 IEEE Global Humanitarian Technology Conference (GHTC)*, 2024, pp. 431–438. doi: 10.1109/GHTC62424.2024.10771549.

[14] Y. M. O. Abbas and K. Asami, "Design of software-defined radio-based adaptable packet communication system for small satellites," *Aerospace*, vol. 8, no. 6, Jun. 2021, doi: 10.3390/aerospace8060159.

[15] Denny Hardiyanto, Samuel Kristiyana, Dyah Anggun Sartika, Irfan Ahmad, and Israa Al_Barazanchi, "Training of dual band HT-based emergency communication tools on member of KTB BPBD, yogyakarta," *Jurnal Pengabdian dan Pemberdayaan Masyarakat Indonesia*, vol. 1, no. 2, pp. 40–48, Sep. 2021, doi: 10.59247/jppmi.v1i2.6.

[16] D. Shin, C. Lee, and S. Choi, "A Conflict-Aware Channel Assignment in Multi-Radio Multi-Channel Wireless Mesh Networks," *IEEE Access*, vol. 12, pp. 14751–14763, 2024, doi: 10.1109/ACCESS.2024.3357142.

[17] I. Q. Utami and F. Ramdani, "GEMAR: web-based GIS for emergency management and ambulance routing," *Inform. Health Soc. Care*, vol. 47, no. 2, pp. 123–131, Apr. 2022, doi: 10.1080/17538157.2021.1948856.

[18] L. Chen, N. Zhao, Y. Chen, F. R. Yu, and G. Wei, "Toward Optimal Rate-Delay Tradeoff for Computation Over Multiple Access Channel," *IEEE Transactions on Communications*, vol. 69, no. 7, pp. 4335–4346, 2021, doi: 10.1109/TCOMM.2021.3068493.

[19] N. Cordeschi, F. De Rango, and M. Tropea, "Exploiting an Optimal Delay-Collision Tradeoff in CSMA-Based High-Dense Wireless Systems," *IEEE/ACM Transactions on Networking*, vol. 29, no. 5, pp. 2353–2366, 2021, doi: 10.1109/TNET.2021.3089825.

[20] H. Ding, M. Li, and J. Zhang, "A CSMA Mechanism with Variable Collision Control and Priority Provision in Multichannel Mobile Ad Hoc Networks," *Mobile Information Systems*, vol. 2021, 2021, doi: 10.1155/2021/4482815.

[21] V. V. Borodin, V. E. Kolesnichenko, and V. A. Shevtsov, "Analysis of the Efficiency of Various Receipting Multiple Access Methods with Acknowledgement in IoT Networks," *Inventions*, vol. 8, no. 4, Aug. 2023, doi: 10.3390/inventions8040105.

[22] M. Espinoza, C. Oberli, M. Gutiérrez Gaitán, and A. Maass, "Channel Access Probability in Unslotted IEEE 802.15.4 csma Under Correlated Clear Channel Assessments," *IEEE Access*, vol. 13, pp. 136671–136686, 2025, doi: 10.1109/ACCESS.2025.3593810.

[23] T.-Y. Kim, L. F. Capon, H. Park, and J.-H. Kim, "A Design of Hybrid CSMA using Sequential-based Scheduling Algorithm," in *2021 International Conference on Information and Communication Technology Convergence (ICTC)*, 2021, pp. 215–217. doi: 10.1109/ICTC52510.2021.9620758.

[24] D. Covaciu, I. Preda, and G. Ciolan, "GPS Based Data Acquisition System for Mobile Applications," 2011.

[25] J. P. Snyder, *Map Projections: A Working Manual*. U.S. Geological Survey Professional Paper 1395, 1987.

[26] "Springer Handbook o*f* Global Navigation Satellite Systems Teunissen Montenbruck Editors."

[27] R. F. Keefe *et al.*, "Positioning methods and the use of location and activity data in forests," May 01, 2019, *MDPI AG*. doi: 10.3390/f10050458.

[28] H. Cui and S. Zhang, "Satellite availability and service performance evaluation for next-generation gnss, rnss and leo augmentation constellation," *Remote Sens. (Basel).*, vol. 13, no. 18, Sep. 2021, doi: 10.3390/rs13183698.

[29] J. Jagelčák, O. Kuba, J. Kubáňová, M. Kostrzewski, and M. Nader, "Dynamic Position Accuracy of Low-Cost Global Navigation Satellite System Sensors Applied in Road Transport for Precision and Measurement Reliability," *Sustainability (Switzerland)* , vol. 16, no. 13, Jul. 2024, doi: 10.3390/su16135556.

[30] S. M. Asaad and H. S. Maghdid, "A Comprehensive Review of Indoor/Outdoor Localization Solutions in IoT era: Research Challenges and Future Perspectives," Jul. 20, 2022, *Elsevier B.V.* doi: 10.1016/j.comnet.2022.109041.

[31] Ø. Hanssen, "Position Tracking and GIS in Search and Rescue Operations," in *Crisis Management - Theory and Practice*, K. Holla, J. Ristvej, and M. Titko, Eds., London: IntechOpen, 2018. doi: 10.5772/intechopen.75371.

[32] J. Jeon, M. Ji, J. Lee, K. S. Han, and Y. Cho, "Deep Learning-Based Emergency Rescue Positioning Technology Using Matching-Map Images," *Remote Sens. (Basel).*, vol. 16, no. 21, Nov. 2024, doi: 10.3390/rs16214014.

[33] C. Specht, "Maritime DGPS System Positioning Accuracy as a Function of the HDOP in the Context of Hydrographic Survey Performance," *Remote Sens. (Basel).*, vol. 15, no. 1, Jan. 2023, doi: 10.3390/rs15010010.

[34] A. Sukhenko, N. Meirambekuly, A. Syzdykov, A. Mukhamedgali, and Y. Mellatova, "GNSS for High-Precision and Reliable Positioning: A Review of Correction Techniques and System Architectures," Nov. 01, 2025, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/app152212304.

[35] K. He *et al.*, "Improving the performance of time-relative gnss precise positioning in remote areas," *Sensors (Switzerland)*, vol. 21, no. 1, pp. 1–24, Jan. 2021, doi: 10.3390/s21010292.